Table of Contents

Abstract

The goal of this analysis is to provide Humboldt State University's Plant Operations with a concise analysis of feasible options for offsetting the energy currently being purchased from Pacific Gas and Electric (PG&E). The analysis consisted of two photovoltaic (PV) solar options, one that would offset 100% percent (20W) of the buildings energy needs, and another that would offset 50% (10kW) of the buildings need, both of which would cover a 25 year period. From the PV analysis it was determined that neither project would be able to recoup the total investment cost within the warranted life of the systems, and are therefore not sound financial investments. The alternatives to these options were comprised of efficiency measures including heating ventilation and air conditioning (HVAC) improvements, increased insulation, and the installation of a solar thermal assisted hot water heater (add more if they exist). For the HVAC system analysis it was determined that the system is so antiquated that a new system would effectively double the efficiency of the system and would save the Natural History Museum $525.66 with a buy back time of 11 years. Installation of the LED replacement bulbs would instantly half the amount of energy purchased from PG&E. The LED installation would save the Natural History Museum $541.90 a year with a buy back time of 9.9 year . The installation of the ceiling fans and solar curtains cannot be quantified until the monitoring techniques are enacted.

Introduction

The site location of this energy analysis is located at 1315 G Street Arcata, CA 95521. The building was once a Wells Fargo Bank, until 1989, when it was acquired by Humboldt State University and then converted into the Natural History Museum. Since then, the building has been open to the general public featuring collections, exhibits and programs that are all meant to inspire an appreciation for the natural world. The Natural History Museum is therefore inherently concerned about environmental issues. Inspiration for this project not only arises from this fact but also from the characteristics of the building itself, which has enormous solar potential with its unobstructed south facing roof. As environmental science students concerned with energy and climate related issues, we were forced to ask the question of why this excellent resource was not being used to accommodate a photovoltaic (PV) array.

While the focus of this report is to evaluate a solar PV array we did not want to overlook other, less expensive, alternatives to offsetting the energy currently purchased from Pacific Gas and Electric. During a walkthrough of the Natural History Museum with Matthew Elliot of HSU Plant Ops we determined what systems could be improved upon. We identified that replacing the HVAC system to have the most positive of impacts potentially due to the old age of the system.

During the walkthrough with Matthew Elliot we also noticed that the returns for the HVAC system were placed 10-12 feet above ground. Since the ceiling of the Natural History Museum stands at 16 feet tall and that the thermostat was placed four feet above the ground we determined there was a huge amount of heat wasted on heating the expansive ceiling area. Due to these parameters we decided to look into ceiling fans to circulate the heated ceiling air down to the optimal area.

The large amount of fluorescent lighting was apparent during the walkthrough. We decided to evaluate the saving of replacing the current florescent bulbs with equivalent LED's. Lastly the only accumulation of windows in the Natural History Museum are located on the North side of the building and are only made of single pane glass in aluminum or wood frames.

Windows on North side of buildings only allow heat to exit since it will not be exposed to any sunlight. We decided that the replacement of such custom sized windows would not be economically feasible. We decided to research the more cost effective option of solar curtains.

An additional alternative analyzed was the installation of a solar hot water heater. Even given its rather large size, the natural history building doesn't use much hot water. There are no showers inside, and no permanent residence live there. This allows for the possibility of a moderately sized solar thermal system to accommodate this building's needs.

Problem Statement

The problem that this project looks to address is the HSU Natural History Museum's dependence on nonrenewable fossil fuels.

Background

Environmental Issues

The current state of energy efficiency and conservation in the United States, especially in older buildings, is average at best. Coal accounts for a major portion of energy production in the U.S., which releases massive quantities of Carbon Dioxide into the atmosphere. These carbon emissions also play a role in ocean acidification, which can be harmful to marine life, and are a major cause of climate instability from greenhouse gases. Additionally, these mining practices are extremely degrading to the environment. Mountain top removal and strip/pit mining are not only visual eyesores, but can also greatly affect the pH levels in rivers and streams, adversely affecting salmonoids and other aquatic creatures. Another common nonrenewable resource used to manufacture energy is oil. Oil is on par with coal in terms of injecting harmful particulate matter into the atmosphere. The use of oil can lead to unavoidable environmental consequences that range from toxic roadway runoff, to large volume spills that can be environmentally devastating, and potentially take decades to neutralize. It has become increasingly clear that energy from nonrenewable resources, if unmitigated, can be extremely detrimental to the environment. Because of this, it is imperative that steps be taken to minimize the consumption and loss of this energy through inefficient and careless use.

Legal Implications

Catastrophic environmental events within the U.S. have sparked controversy about standard practices and have, at times, spurned the creation of major legislation to deal with the problem. The Cuyahoga River catching fire in 1969 helped legislators draft the Clean Water Act of 1972. When 200 people died in New York City due to smog Congress drafted the Clean Air Act the same year. The same law was amended to create a cap and trade agency in 1990 to drastically reduce the emissions of SO2 and NOx that were the key chemicals responsible for acid rain.

Unfortunately in the past several years, with the threat of global climate change looming, the U.S. government has not heeded or acted on the recommendations of the world wide scientific community. The U.S. has ignored the remediation or restriction techniques offered by the International Panel on Climate Change and the United Nations sponsored Kyoto Protocol. Recent history portrays the U.S. governments approach to global climate change to be a "wait and see" approach.

Fortunately for Californians their state government has always been on the forefront of environmental protection in the U.S. Governor Arnold Schwarzenegger wrote an executive order in 2008 specifically to, "reduce global warming and greenhouse gas emissions, increase renewable energy production, promote energy efficiency, energy conservation, clean air and emission controls, expand the use of low carbon, alternative fuels and promote and commercialize new technologies and industries;"*1. This executive order calls for a Renewable (energy) Portfolio Standard that requires sellers of electricity shall serve 33% of their load with renewable energy by the year 2020. Gov. Schwarzeneggers' executive order has led the way to many renewable energy programs such as California Solar Initiative that allocates $2.2 billion in solar panel installation rebates.

Economics of Renewable Energies

Over the last century the United States has experienced impressive economic growth. This growth is fueled largely by the presence of abundant and readily accessible fossil fuels. Unfortunately due to the finite availability of these fuels, this growth is not sustainable in nature. This is evident in the rising cost of fossil fuels that has resulted from their decreased availability, and the increasing energy required extracting and processing them. With rising fossil fuel cost, investment in new renewable energy technology is becoming more attractive financially. This increase in renewable energy's appeal is based on a simple economic concept known as opportunity cost.

Opportunity cost is the idea that in a world of finite resources, every decision of how to allocate those resources will have a set of associated advantages and disadvantages. For example, if a power company was to build a new coal fired generator, a benefit would be more electricity supplied to the grid, and a cost would be increased emissions of greenhouse gasses. The goal of examining the opportunity cost of a given action is to maximize the desired benefits, and limit the cost. When done effectively, an implemented process is said to be economically efficient. For years many renewable energy sources have been plagued with high prices relative to the well-established fossil sources. However this difference in price ignores the social and environmental cost of consuming fossil fuels. Some of these costs, which economists call externalities, are fiscal, such as government tax subsidies. Others are harder to quantify, such as greenhouse gas induced climate change. Adding these external costs to the already increasing prices for fossil fuels can dramatically close the gap between traditional and renewable energy resources.

Another important factor to consider when looking at the externalities of fossil fuel use is that some impacts can take long periods of time to take effect. This means that future generations are inherently burdened by our choices, and that our generation will not see many of the benefits of more responsible resource consumption. This long time span also increases the complexity and uncertainty in the calculation of climate change abatement. One important concept to consider when looking at investments over long time periods is discount rates. Simply put a discount rate is the rate of return that is required to make an investment financially viable compared to other possible options. Discount rates, which will be discussed further in the analytical portion of this report, can easily be calculated for most investments. However the social complexities of issues such as anthropogenic climate change can cause the calculation of such rates to be heavily disputed, and change dramatically depending on what moral assumptions are taken into consideration. Because of this, valuing the cost of mitigation measures can be very difficult.

What Being Done on School Campuses

Schools throughout the state have been increasingly considering alternative energy solutions as a way to offset their annual energy expenditures. PV installations on school building rooftops are one of the many ways in which schools are doing their part in reducing future hikes in cost to their students, as well as, addressing the calamity of global climate change. In California it is no mystery that school budgets are shrinking and costs for school operations keep going up. Identifying the most cost-effective energy saving opportunities and reducing annual utility expenditure not only saves money for the school but also conserves finite resources. Therefore, by investing in alternative energy, schools are not only improving the qualities of lives of it students but for the global community as well.

California is often considered a pioneering state when it comes to alternative energy production and is easily the largest single center for solar energy production nationwide. For the past several years the solar industry has grown drastically despite trying economic times. This is due in part by reductions in costs associated with solar PV modules as well as costs associated beyond the modules themselves, such as the cost of installation, overhead, balance of systems and other non-module costs. Furthermore, creative ways to finance solar installations have made the prospect of alternative energy much more inviting.

For schools in California, the typical choices for financing such projects include third-party ownership otherwise known as power purchase agreements (PPA), cash purchase, or publically funded aka general obligation bonds.

PPA arrangements consist of a third party owning and maintain the PV system installed on campus. This third party then charges the school for the energy generated by the aforementioned system, which is usually based on a pre-negotiated price. The school, in turn, will witness savings from a reduced electricity bill directly resulting from the energy being offset by the production of electricity the new system provides. The PPA is often the best financial alternative for schools to make when considering solar because as non-profit entities this means they are ineligible to qualify for the 30% federal investment tax credit. This is where the third party plays the most important role, because as the system owner, third parties are able to take advantage of such opportunities. The above scenario benefits both parties economically in that the 30% savings is reflected in cost to non-profit entities.

Cash purchases are also another route in which schools in California are funding solar project. However, this option is often less attractive especially when projects are large in scale and upfront costs are high, as well as, ineligibility for tax incentives.

The third and final way in which most projects have been funded are through publically funded/general obligation bond, Otherwise referred to as a GO bond. This method insures little to no upfront costs and is therefore favorable to schools because they can realize savings through reduced electricity costs without upfront costs. However GO bonds are not always available to schools and must first be approved by local governments or voters.

In addition to choosing the right most appropriate method of funding, schools throughout California have been working with utilities to determine which rate schedules make their newly installed systems the most valuable. For instance PG&E offers schools with several options in which they are charged for the electricity they consume. Some of the most common types of rates include, flat rates, seasonal rates, time of use rates, demand charges, and tiered or block rates. In California it has become clear the value of electricity generation is highly dependent on the schools electricity rate schedule. Understanding what rate structure works best for a schools specific building load and PV generation is essential when evaluating and optimizing savings.

Dirty Habits

In 2011, 90.3% of energy used in the United States came from nonrenewable sources. 36.2% from oil, 25.2% from natural gas, 20.4% from coal, and 8.5% from uranium. They are considered nonrenewable because their supply is limited and can not be reproduced, grown, generated or used on a scale which can sustain its consumption rate. Nature cannot produce as fast as we consume. Once depleted, there is no more available for future use.

Oil, crude and petroleum, comes from reserves and wells under the earth's surface. It is extracted from the process of drilling into the earth and pumping the oil out. It is sent to a refinery where it is separated and transformed into different useable petroleum products. Drilling disturbs many natural earth dynamics, cycles, and habitats and is primarily done offshore in our oceans. It is not a perfected system and many problems do occur. Oil is frequently spilled into the ocean contaminating the water, killing lots of ocean and often terrestrial life, and cascades detrimental effects down the food chain and through ocean cycles. Oil drilling and refining are both very energy intensive processes that release a variety of different emissions into the air contributing to increasing levels of greenhouse gasses in the atmosphere.

Natural gas it the second largest source of energy in the United States. One process that natural gas is extracted from the earth is known as hydraulic fracturing, or fracking. This is a process that drills a hole down into gas reservoir rock formations. A highly pressurized mixture of water and chemicals is injected into the cracks to further open the reserve for collection of the gas. This is an unperfected system that potentially creates further environmental problems. Land must be cleared in order to install these fracking sites disturbing natural habitats and destroying resources in that area. This process taps into the tectonic system and creates unnatural disturbances in the earth's plates forcing minor, and sometimes major, earthquakes to occur and shifts plates into vulnerable positions. The holes that are drilled into the ground often pass through the water table and gas is leaked into our water supply contaminating the water making it highly toxic. In many places, tap water can be lit on fire by simply putting a match up to a faucet because of gas and chemical contamination due to fracking. There is also a risk of gas leakage that contaminates the air we breath and increases the amount of greenhouse gasses in the atmosphere, which ultimately exacerbates global climate change.

Coal is the third most abundant source of energy used in the United States. It is formed in the earth and extracted through different energy intensive extraction processes. Coal mining tears up the earth and obliterates the land that is being mined. It destroys habitat, displaces animals, kills animals and plants, pollutes the surrounding land, and destroys resources. All the machinery used to dig coal out of the ground emits a large amount of pollutants and gases into the atmosphere. Coal companies blow off the tops of mountains in order to gain easy, yet catastrophic, access to coal reserves. All functions of this process pollute the land, water, and air. It contributes to increasing levels of greenhouse gasses in the atmosphere and destruction of resources.

Goals and Objectives

Goal

The goal of this project is to generate a report that can be referenced by Humboldt State University's Plant Operations so as to inform any future attempts that will likely be made to address the Natural History Museums energy usage. With a focus on environmental benefits, options that offset energy use with cleaner sources, improve upon energy efficiency or decrease usage all together will be presented. In the end, decreasing annual energy expenditure for the museum, as well as, its environmental impact is what motivates this research.

Objective

Appropriately size a photovoltaic system that would offset 100% of the buildings electrical needs and explore its financial feasibility.

- Alternative 1: Offset 50% of current energy being purchased from Pacific Gas and Electric by the HSU Natural History Museum through the installation of a photovoltaic solar system.
- Alternative 2: Offset 50% of current energy being purchased from Pacific Gas and Electric by the HSU Natural History Museum through HVAC upgrades and efficiency improvements.

- <u>Alternative 3:</u> Offset 50% of current energy being purchased from Pacific Gas and Electric by the HSU Natural History Museum through the installation of a solar thermal assisted hot water heater.
- <u>Alternative 4:</u> Offset 50% of current energy being purchased for lighting from Pacific Gas and Electric by the HSU Natural History Museum through the installation of LED equivalent bulbs.

Methodology

PV Analysis

The necessary steps needed to size a PV system

- Obtain energy use history documentation from Humboldt State University's Plant Operations to determine average daily building load for the Natural History Museum.
- Determine an annual average amount of hours per day for site location that photovoltaic system will be able to generate electricity.
- Determine a likely balance of systems value.
- Calculate system size in kilowatts.

Cost Analysis

The steps in conducting the cost feasibility of the PV system included

- Determine the upfront cost
- Determine the lifecycle cost

  - Calculate the future costs of inverter replacement

  - Account for maintenance cost

- Determine the lifecycle benefits

  -Total offset energy cost

- Calculate cost and benefits in terms of net present value
- Determine payback period

HVAC

The evaluation of the current and possible future HVAC system was made by consulting experts. Matthew Elliot of HSU Plant Ops informed us of the history of the system. Nathan Miller of California Heating Supply evaluated the current system and supplied a quote for a new system and for replacing the current antiquated ducting.

Lighting

We researched the type of fluorescent lights that are used at the Natural History Museum, such as watts used, life time, and price of each bulb. We then counted the number of fluorescent light bulbs. Then we weighed those figures versus the hours of operations. We then compared that to an average price, watt usage, life time, and price of online available equivalent LED bulbs.

Air Circulation

By measuring the cubic feet of the ceiling area we were able to determine the amount of heated air that was wasted in the high ceiling. By evaluating the ceilings current electrical installation we determined that six ceiling fans could be installed in the ceiling. We then found a fan that was widely available that was the lowest price for the amount of cubic feet that could be circulated by the fan.

Solar Curtains

We measure the square footage of the windows surrounding the entrance of the Natural History Museum. We then averaged solar curtain prices, per square foot, from several available online stores.

Solar Hot Water

To find the payback time of the solar thermal system, first the solar insolation value of Humboldt County needed to be found. Along with this information, the total surface area of the solar collectors and their associated efficiency was also needed. Lastly, the total amount of time that these solar collectors would be operating was factored into the equation. All of these components multiplied together yielded the total energy (in kilowatts) saved per year. After the total kilowatts were converted to therms, the total cost of the system needed to be divided by the total number of saved therms multiplied by the cost per therm. This equation yielded to total number of years it would take for the proposed system to pay itself off.

PV Analysis

System Size

Average Daily Building Load

The PV system sizing calculation began with an average daily building load value that was determined from energy use history documentation provided by Humboldt State University's Plant Operations (Appendix A). Data from the documents was compiled into an excel spreadsheet to allow for further investigation. In graphing electricity use over time it became clear that usage was inconsistent over the amount of time data was provided. This is believed to be attributable to the history of the museum, which in the past experienced more use and even closure. Therefore, In order for the future PV system to meet the most likely building load, a time interval was defined based on the most recent trend in electricity usage for the museum. The arrow on the graph below indicates the initial time of which to base PV system size; this also corresponds to about the same time of the museums reopening in 2010. Neglecting data that reflected higher usage and closure of the museum's past was justified by no evidence of future closure or foreseeable increase in energy use.

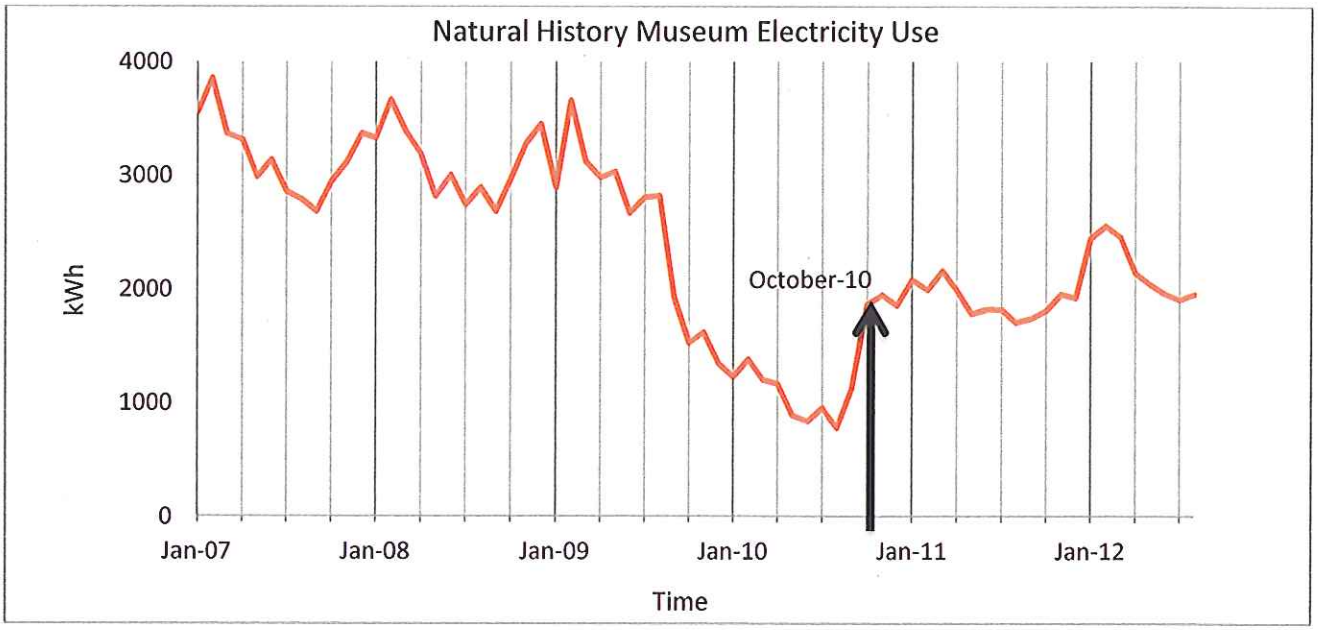
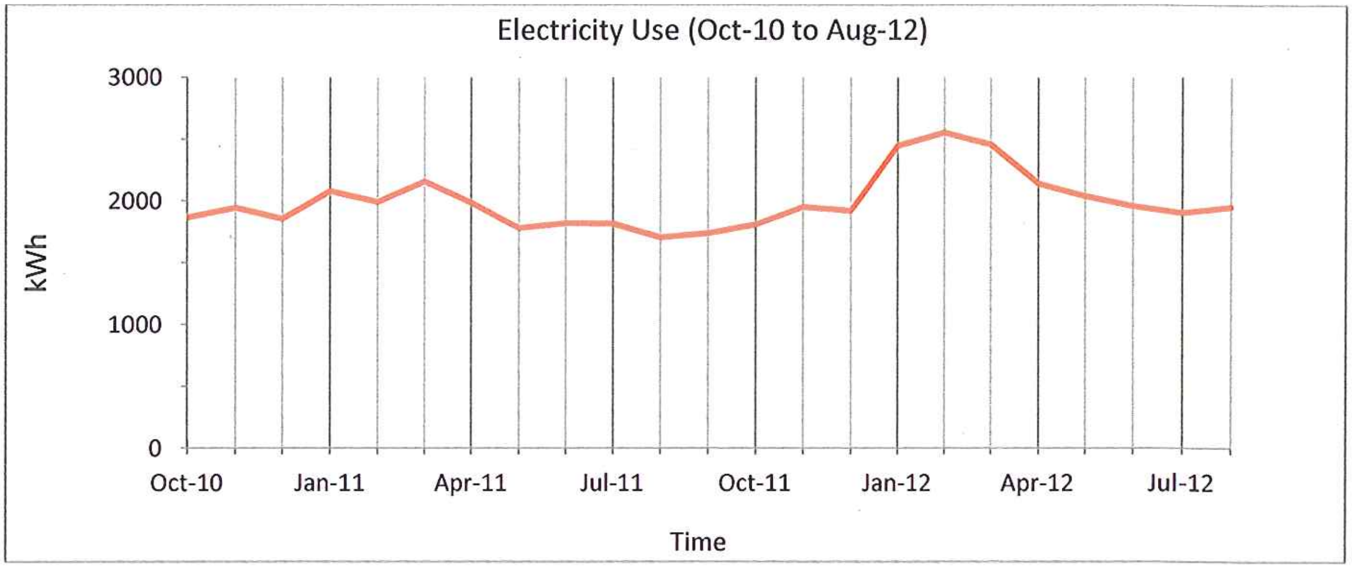


Figure 1: Humboldt State University, Natural History Museum electricity use in kilowatt hours from jan-07 – Aug12. Source (Appendix A)

The period from October 2010 to August 2012 was thereby chosen to be the most accurate time interval of which to base PV system size calculation. Graph and chart below represents electricity usage of interest for this report.



1315 G Street Arcata, CA 95521		
Electricity Usage Oct-10 to Aug-12		
current_read_date	*Total Usage (kWh)*	*num_days*
August-12	1953	29
July-12	1905	32
June-12	1959	30
May-12	2041	30
April-12	2140	31
March-12	2458	30
February-12	2554	29
January-12	2447	33
December-11	1921	29
November-11	1953	30
October-11	1810	31
September-11	1740	30
August-11	1705	29
July-11	1818	32
June-11	1820	30
May-11	1782	29
April-11	1986	31
March-11	2156	31
February-11	1991	29
January-11	2080	32
December-10	1855	30
November-10	1945	30
October-10	1866	31
Total	45885	698

Figure and Graph: Humboldt State University, Natural History Museum electricity use in kilowatt hours from Oct-10 to Aug-12. Source (Appendix A)

With a proper time interval established, total amount of electricity and amount of days in period was used to determine the average daily building load. From October 2010 to August 2012, or for 698 days, the Natural History Museum's load was totaled to approximately 45,885kWh. Average daily building load (E_{daily}) which most useful when expressed in watt hours (Wh) per day, is calculated as follows:

$$E_{daily} = \frac{45{,}885\cancel{kWh}}{698 Days} = \frac{10^3 Wh}{\cancel{kWh}} = 65{,}738\ Wh/Day$$

The Natural History Museum used on average 65,738 Wh a day for the past 698 days. It is important to calculate this value because average daily building load will ultimately dictate PV system size, and therefore system cost and space needed. In addition to average daily building load, other variables are included in the PV system sizing calculation such as; the amount of available solar resource at site location and the balance of systems or DC-to-AC derate factor.

Amount of Available Solar Resource

Determining amount of solar resource available at a given location can be achieved by measuring the amount of hours per day of full sun exposer. This will also be the amount of time the PV panels will be able to generate electricity on any given day. The fact that a greater number of hours exist in the summer compared to the winter requires the need for an annual average value in calculating PV system size. Fortunately, this does not require the need to measure every single day throughout the year. The national renewable energy laboratory (NREL) has a free online program called PVWATTS that does this painstaking task for you. The program also factors in site specific meteorological data which is specifically useful for areas like Arcata, CA that experience several days a year of 100% could cover.

Imputing the HSU Natural History Museum's address (1315 G Street Arcata, CA 95521) into PVWATTS results in an average annual solar resource of 4.29 kWh/m^2/day.

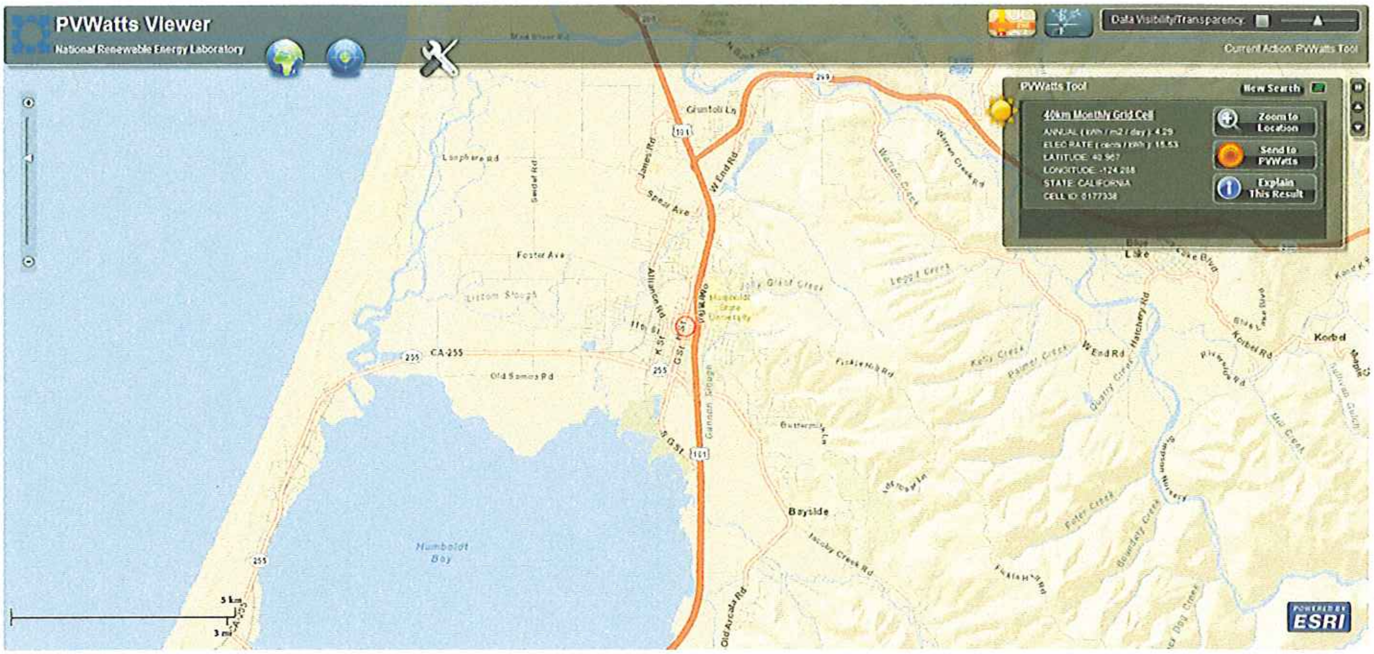


Figure 2 National Renewable Energy Laboratory PVWatts viewer

The resulting value is reported in kWh/m^2/day which is not preferable for this type of PV system size calculation. To get this value into the more usable form of hours per day simply divide by peak solar irradiance of the sun (1000W/m^2).

$$Full\ Sun = \frac{Average\ Daily\ Insolation\ \ kWh/m^2/day}{Peak\ Irradiance\ kW/m^2} = \frac{4.29\ \cancel{kW}h\ /\cancel{m^2}/day}{1\ \cancel{kW}/\cancel{m^2}} = 4.29h/day$$

Balance of Systems

In PV system sizing calculations, balance of systems (BOS), or direct current (DC) – to - actual current (AC) derate factor, is a tabulated value that is used to over size an array to compensate for losses that will be expected from "panel to plug" of PV system components. For instance, when DC is generated by a PV panel and then converted to AC via an inverter, energy is lost in the form of heat. Other losses that are expected, exists as energy is transferred over a distance in both the DC and AC wiring of the system. Needless to say, it is very important to account for losses in order to properly size the PV system that will meet the average daily building load. For this calculation PVWATTS was used to determine a BOS value. The below image is a summary and methodology of how a PVWATTS BOS value is determined.

DC-to-AC Derate Factor

The PVWatts calculator multiplies the nameplate DC power rating by an overall DC-to-AC derate factor to determine the AC power rating at STC. The overall DC-to-AC derate factor accounts for losses from the DC nameplate power rating and is the mathematical product of the derate factors for the components of the PV system. The default component derate factors used by the PVWatts calculator and their ranges are listed in the table below.

Derate Factors for AC Power Rating at STC

Component Derate Factors	PVWatts Default	Range
PV module nameplate DC rating	0.95	0.80–1.05
Inverter and transformer	0.92	0.88–0.98
Mismatch	0.98	0.97–0.995
Diodes and connections	0.995	0.99–0.997
DC wiring	0.98	0.97–0.99
AC wiring	0.99	0.98–0.993
Soiling	0.95	0.30–0.995
System availability	0.98	0.00–0.995
Shading	1.00	0.00–1.00
Sun-tracking	1.00	0.95–1.00
Age	1.00	0.70–1.00
Overall DC-to-AC derate factor	0.77	0.09999–0.96001

The overall DC-to-AC derate factor is calculated by multiplying the component derate factors.

For the PVWATTS default values:

Overall DC to AC derate factor

= 0.95 x 0.92 x 0.98 x 0.995 x 0.98 x 0.99 x 0.95 x 0.98 x 1.00 x 1.00 x 1.00

= 0.77

The value of 0.77 means that the AC power rating at STC is 77% of the nameplate DC power rating. In most cases, 0.77 will provide a reasonable estimate. However, users can change the DC-to-AC derate factor. The first option is to enter a new overall DC-to-AC derate factor in the provided text box. The second option is to click the **Derate Factor Help** button. This provides the opportunity to change any of the component derate factors. The derate factor calculator then calculates a new overall DC-to-AC derate factor.

Figure 3 4 National Renewable Energy Laboratory PVWatts viewer

System Size Calculation

Now that the aforementioned values have been determined, PV system size is calculated using the following equation.

$$P_{PV} = \frac{E_{daily}}{Full\ Sun * \eta_{BOS}} = System\ Size\ (Watts)$$

Where: $P_{PV} = PV\ power\ (watts)$

$$Full\ Sun = 4.29h/day$$

$$E_{daily} = 65{,}738\ Wh/Day$$

$$\eta_{BOS} = 0.77$$

Equation solved:

$$P_{PV} = \frac{65{,}738\ W\cancel{h/Day}}{4.29\cancel{h/day} * 0.77} = 19{,}901\ Watts$$

The museum therefore needs a 19.9 kilowatt (KW) PV array to meet 100% of its electrical load.

Number of Panels

Determining the number of panels that are required for a 19.9 kW system is straightforward. Simply divide P_{PV} in watts by the panel's nameplate DC power rating. For instance if a 300W panel is selected, number of panels is calculated as follows:

$$N_{PV} = \frac{19{,}901\ W}{300W} = 66\ panels$$

Analysis of Results

With an average daily building load of 45,885kWh, it has been determined that the Natural History Museum would need a 20kW PV array to completely offset its demand. This size of system would amount to approximately 66 300W panels. Given the extensive amount of usable roof space on the Natural History Museum, 66 panels could be easily accommodated. Of course, it is worth noting that number of panels is indirectly proportional to panel wattage, i.e. a lesser panel wattage results in a greater number of panels, and vice-versa. In the likely event that a smaller system is adopted, the table below demonstrates the relationship between number of panels and percent of demand that will be met by PV generation (PV penetration).

System Size and Number of Panels			
PV Penetration	*E_daily*	*System size kW*	*N_PV*
100%	65737.8	19.9	66
95%	62450.9	18.9	63
90%	59164.0	17.9	60
85%	55877.1	16.9	56
80%	52590.3	15.9	53
75%	49303.4	14.9	50
70%	46016.5	13.9	46
65%	42729.6	12.9	43
60%	39442.7	11.9	40
55%	36155.8	10.9	36
50%	32868.9	10.0	33
45%	29582.0	9.0	30
40%	26295.1	8.0	27
35%	23008.2	7.0	23
30%	19721.3	6.0	20
25%	16434.5	5.0	17
20%	13147.6	4.0	13
15%	9860.7	3.0	10
10%	6573.8	2.0	7
5%	3286.9	1.0	3

Table 1 System size and number of panels (assuming: $Full\ Sun = 4.29h/day$, $\eta_{BOS} = 0.77$ and panels are 300W)

System Cost

A major parameter for determining whether or not a PV Solar array is a feasible option for offsetting HSU's electrical demand is its return on investment. If the return on the investment is less than the cost of the system, then financially the project will be at a loss. A project can still be a viable option even if it doesn't produce a fiscal return on investment, as there are often other non-monetary gains. However, if a project is not capable of paying for itself, then limited funding will significantly hinder its feasibility.

The first step in the financial feasibility analysis was determining the upfront cost and lifetime of the system that would be invested in. The lifetime is defined as how long the system will produce enough electricity to meet the project need. According to the manufacturer, the panels are warrantied to produce no less than 80% of their initial output for 25 years. This makes our system's guaranteed lifetime 25 years. This also means that the original system size must be augmented to reflect the expected degradation of electrical output. To compensate for the 20% of potential electrical production loss, the initial system size of 20kW must be sized up by 20%, making the required system size 24kW. Using material quotes from Wholesale Solar and Todd Corry, an experienced solar installation technician, an upfront investment cost of $95,350 was generated. Added to this was Arcata's 9% sales tax, which added $8,581.50, making the total system cost $103,931.50. In a partnership with the state of California, Pacific Gas and Electric offer a rebate known as the California Solar Initiative, which currently will absorb PV solar system cost by $0.70for every Watt constructed for projects up to 30kW(The

World Bank 2011). For the proposed project this rebate would equate to a savings of $16,800, which would bring the total upfront system cost to $87,131.50 (appendix B). There is also an active federal tax credit available that will cover up to 30% of a new PV systems cost, however, because HSU is already a tax exempt institution, it will not be able to take advantage of this.

The cost of this system in not limited to the initial investment. Because of this, the next step is a lifecycle cost analysis. The system will require maintenance, such as cleaning and repair. It is assumed that the cost of this maintenance will be $100 per year, which will pay for the plant operation workers' time devoted to the system and replacement parts. The inverters for the system are warrantied for ten years, so it will also be assumed that each inverter will need to be replaced when this warranty expires. According to a study by Navigant consulting (2006),the cost of solar inverters is decreasing by 2% in real terms every year. "Real terms" means that the 2% decrease will be in addition to depreciation due to general inflation. Considering this, the future cost can be calculated using the equation:

$$FV = PV \cdot (1 + i)^n$$

Where **i** is the interest rate (-2%,) and **n** is the number of periods before the investments are made in 10 and 20 years. Using this formula, the first inverter replacement cost is predicted to decrease from $9,026 to $7,374.90; for the second inverter, this cost will decrease an additional $1,349.07 to $6,025.83. Using the present value equation:

$$NPV = \sum_{i=1}^{n} \frac{values_i}{(1 + rate)^i}$$

Where **rate** is the real interest rate (.5%)(The World Bank 2011), and **j** is the number of periods from now (period 0) until the end of the equipment's life (25 years), the lifecycle cost of this system was calculated to total $101,760(appendix C).

It is important to note what is happening in the denominator in the equation above. One is being added to the real interest rate and this sum is then raised by the number of years that the investment will be made. This calculates the system's annual relative depreciation in value at a rate of .5%. This relative depreciation is the result of having a real interest rate of .5%, which means that the upfront capital cost of this system could otherwise be invested in a savings account with a return of half a percent every year. So, by investing in this solar project, the investor is giving up on earning the potential income of .5% on the initial system cost every year. When interest rates are considered in this fashion they are known as discount rates, because they effectively reduce (discount) the return value of an investment.

Now that the total lifecycle energy production and the total cost of the system have been calculated, the Levelized cost of energy (LCOE) can be calculated with the equation:

$$\left(\frac{\boldsymbol{Lifecycle\ Cost}}{\boldsymbol{Lifecycle\ kWH}}\right) = \boldsymbol{LCOE}$$

Doing this gives an energy generation cost of approximately $0.156 per kWh hour (Appendix C). This value is $0.058 higher than the current average price of $0.098 per kWh being paid by Plant Operations. This is an indicator that the system will not be able to recover its cost during its lifetime.

Now that the cost of the system is well defined the next step is to determine the fiscal benefit of investing in the system. Financial return on this project will come from offsetting the energy demand for the building, and in turn canceling out the electrical fee currently being paid to PG&E. To do this, it will be assumed that the building's electrical usage in 2011 will be representative of average future consumption. HSU Plant Operations' PG&E billing statement for 2011 shows that the building's cumulative energy usage for the year was22762kWh. The total cost for this energy was $2,223.91. This cost is predicted to rise annually by at least half a percent over general inflation. To get the total lifecycle benefit for this project, the 2011 cost was compounded each year at .5% and the values were then summed. Doing this gave a total avoided cost of $55,321 (Appendix D). This value is $46,439 less than the total system cost of $101,760, so to implement this project Plant Operations would have to accept an un-recuperative cost of $46,439.

Given an outstanding balance at the end of the warrantied lifetime of the system, the financial analysis could stop here. However, for added clarity, another NPV calculation was made for the net cash of the system. This was done using the real interest rate of .5%, as well as two hypothetical interest rates of 3% and 5%, which simulate potential rises in interest rates into the future. The NPV for these interest rates were calculated at -$49,312, -$58,638, and -$63,747 respectively. An internal rate of return (IRR) of -5% was also calculated for this project by averaging the percentage difference in the system cost and benefit. For favorable financial investments the IRR will be greater than the interest rates (discount rates).Unfortunately, the IRR of -5% generated by this analysis is not greater than even the lowest interest rate considered, and this system will not be able to recover its investment cost during its warranted lifecycle (appendix E).

The primary reasons for this project's inability to repay its investment cost are: the relatively low price being paid electricity, the additional cost of scaling up the system to account for productivity degradation without being able to sell the additional electricity, and the fact that HSU is tax exempt, and therefore cannot take advantage of a federal rebate that would cover 30% of the total system cost. Considering these implications, a half sized system alternative was also analyzed. This system would also hindered by low energy cost, but it any energy produced due to system scaling would no longer be in excess and would still offset the systems cost. The procedure was the same with the full system, but with the new cost and benefit values supplemented where appropriate. The total upfront cost of the second system was calculated to be $37,766 (appendix G), the total lifecycle cost would be $46,160, and the LCOE would be $0.138 per kWh (appendix H). The NPV of the lifecycle benefit for this project would be $35,968, making this project -$10,564 shy of paying itself off during its warrantied lifecycle.

Alternatives

-Other options, besides PV solar array, that could attain desired results.

HVAC

In order to diagnose if the current HVAC system should be repaired or replace we met with Matthew Elliot from HSU Plant Ops. Mr. Elliot had a long personal history with the HVAC system of the Natural History Museum since he had worked on the system when the building was still a Wells Fargo Bank. He informed us that the system was moved from ground level to the attic in the early 1980's due to flooding. He also informed us that the system could be 50 plus years old.

Upon further inspection the HVAC system was made by Payne, model # 100D42-19. The system has one supply and two returns to heat the building. The Payne down flow HVAC uses

100,000 BTU's to delivery 80,000 BTU's, giving it a rating of 80% efficiency. The system was rated at 80% 50 plus years ago. Mr. Elliot reckoned that the efficiency of the system would be 30% less than the manufacture efficiency by now.

Since the system is in the attic, and since there is not a crawl space under the building the two returns are located 10 feet above the ground. This is very inefficient since the HVAC must first heat the vaulted ceiling of a very large room before the heat reaches the thermostat located five feet from the ground.

The owner of California Heating Supply Nathan Miller met with us to give a professional option of what could be done to improve the HVAC system of the Natural History Museum. Mr. Miller reinforced Mr. Elliots views on the Payne system that the system would be 30% less than the manufacture efficiency of 80% 50 plus years ago. Mr. Miller did point out many other problems with the current HVAC system. Such as the furnace, the returns, and all the ducting were not properly insulated or sealed. Only two ducts were insulated, and none of the connectors were insulated. Only two connections were sealed, and it was sealed with duct tape, not the optimal aluminum foil tape.

Lighting

The Natural History Museum currently uses 210 four foot long T8 fluorescent bulbs. These bulbs have a lifespan of 6000 hours, they use 32 watts of energy, they contain mercury, and they cost $1.50 apiece (Ushio 2012). In comparison an LED replacement bulb will last 50,000 hours, use 16 watts of energy, does not contain mercury, and cost $38.00 (Magnalight 2012) apiece.

Air Circulation

All of the heating returns in the main room of Natural History Museum are 11 – 12 feet above the ground. The HVAC system has to heat the entire expansive ceiling before it can be registered by the thermostat which is located four and one half feet above the ground.

The best way to for the main room to be heated without wasting heat in the ceiling would be to reroute the ducting to floor vents. This approach is not viable because there is not a crawl space under the building. The foundation is a concrete pad on top of compacted earth.

A cost effective way to homogenize the warm air in the ceiling and the cooler air towards the ground would be to install ceiling fans. By having the hot air circulated around the room the thermostat would reach optimal temperature and switch off in less time than normal. The Natural History Museum would see a decrease of natural gas usage due to the HVAC system being on less time. There is available electricity in the conduit that supplies the ceiling lights, so there would be no need to install additional conduit. The ceiling fans should be installed in between each cluster of ceiling lights nearest the peak of the ceiling resulting in a total of six fans.

Solar Curtains

The Natural History Museum has approximately 261 square feet of windows located on the north side of the building. These windows are single pane in an aluminum and wood frame. The location of these windows have the ability to lose a large amount of heat without gaining any from the sun. We believe that the replacement of the these large custom windows would be cost prohibitive to replace. An alternative would be to install solar curtains that could be retracted during open hours.

Solar Water Heater

Another possible alternative for the Natural History building would be the installation of a solar hot water heater on the rooftop. There are two types of active solar hot water heaters: direct and indirect. The best of these choices for this particular building would be the direct solar option. This method forces heated water from the solar collectors directly into the dwelling, and is best used in climates that rarely experience severe cold snaps. The latter option uses an anti-freeze fluid and a heat exchanger to transfer its stored energy to water in a separate vessel. This indirect method is best used in areas that regularly experience frigid temperatures and, because of Humboldt's temperate geographic location, doesn't prove to be the best option ("Heat your water," 2003). Additionally, the transition to solar hot water would require a solar collector to capture the sun's energy.

There are several different types of solar collectors on the market, but the best option for the given conditions would be an evacuated-tube collector. These models feature an array of vacuum-sealed tubes which absorb solar radiation and inhibit its escape via multiple layers of insulated glass. They are able to operate sufficiently well in overcast conditions, and the natural history building's roof is south-facing and un-shaded, making it an ideal candidate.

Analysis of Alternatives

HVAC

Upon inspection Mr. Miller suggested three options.

1. Replace the furnace with a new 95% efficient system. An increase of 35% to 45% efficiency.

2. Replace all ducting and connections with R-8 insulated ducting and connections. An increase of 5% to 8% efficiency.
3. Replace the furnace with a new 95% efficient system, and replace all ducting and connections with R-8 insulated ducting and connections. An increase of 40% to 53% efficiency.
    a. Below is the quote provided by Mr. Miller from California Heating Supply

Natural History Museum

Option 1

We propose to furnish material and labor to remove two existing furnaces in attic and replace with two new Lennox ML195DF090XP60C 88,000 BTU 95% efficient single stage furnaces with new PVC flues, condensate lines, drip pans, tie to existing gas and electric supply, new seven day programmable thermostats, disposal of old furnaces, and permit.

PRICE: $ 4,600.00

Option 2

Add to above price to seal, and insulate all bare steel ducting for both systems supply and return ducts except outside air ducts.

PRICE: $ 455.00

WARRANTY: All labor, material and design shall conform to all applicable City, County and State codes. Price includes Lennox ten year parts warranty.

Note: Option one does not include the price of an engineer. Mr. Miller declared that he would need an engineer to draw up plans for the installation of new furnaces.

The last option that could be adopted by HSU Plant Ops would be to seal all connections and the two furnaces with industrial aluminum foil tape. At $33 a roll the whole system could be sealed with two rolls plus labor. This would increase the efficiency of the system by 2% - 5%.

Buy Back Time and Savings

95% efficient HVAC - $4,600

R8 insulated ducting - $455

Engineer (approx) - $750

Total - $5,805

Avg of 46% more efficient HVAC system

2011 Total therms 1105, at $1.03 (including taxes)

Total savings per year with an average of 46% more efficient system is $525.66. Buy back time for the new system would be 11 years.

LED Lighting

Buy Back Time and Savings

The Natural History Museum uses all of their lights during hours of operation, Tuesday – Saturday 10am – 5pm. All 210 lights are used for 35 hours a week at 9.6 cents per kWh.

$0.096/kWh*[(35 hrs/week*4weeks/month*32 watts*12month/yr*210lights)/1000watts)]=$1083.80 Fluorescent Energy Usage/year

$0.096/kWh*[(35 hrs/week*4weeks/month*16 watts*12month/yr*210lights)/1000watts)]=$541.90 LED Energy Usage/year

Total LED Price (minus the 8.3 Fluorescent bulbs needed to match the lifetime of each LED)

(210bulbs*$38 LED)-[((50,000LED Life/6000 Fluorescent Life)*$1.50Fluorescent)*210 bulbs]=$5355 Total LED Price

$5355 Total LED Price/$541.90 LED Saving/year=9.88 years

Buy back time of the LED's =9.88 years

Air Circulation

The recommended fans to be installed are the Westinghouse 56 inch Industrial 3-Blade Ceiling Fan. These fans are quiet, have a low profile, and can efficiently circulate 300 sq ft each. These fans can be found at main online store for $50, total for all fans would be $300 (Home Depot 2012).

Solar Curtains

Solar curtains are made of metalized polyethylene. They are made to prevent heat loss and reflect heat back into the room. Solar curtains are available widely on the internet for approximately $0.25 a square foot (Amerimark 2012). Purchasing price for solar curtains for the Natural History Museums window will cost $65.25.

Solar Water Heater

Currently, this building features a relatively new 68 gallon water heater which uses natural gas for fuel. It operates with an average energy consumption of 242 therms per year which, at $1.03/therm, translates into a $249.26 yearly cost (Alexander, 2012). The average price of a solar thermal system (including installation fees) necessary to accommodate the natural history building's needs is approximately $5,500("Solar thermal costs," 2012). California offers a cost reduction incentive program for solar thermal projects, which reimburses owner $14.53 per therm saved. As shown in the calculation below, this would effectively reduce this cost to \$2,981("Database of state," 2011). The solar collector would require 40 evacuated tubes to accommodate this building's hot water demand, which would require an area of 4.4m2("Solar collector sizing," 2012). These evacuated tubes have an efficiency of approximately 70%. Additionally, Humboldt county has a solar energy potential of 4.52kWh/m2/day (Department of Energy, 2012). Given these metrics, the total amount of kilowatt hours saved each year by this proposed system can be calculated as follows:

(4.52kWh/m2/day)(4.4m2)(.70)(365 days/yr) = 5,081 kWh/yr

Because the energy of the current hot water heater is measured in therms, the above total must be also be converted to therms. There are approximately 29.31kWh in one therm. Hence, (5,081.38 kWh)/(29.31 kWh/therm) = 173.37 therms/yr. Finally, the total payback time (in years) can be calculated as follows:

\$2,981/((173.37therms/yr)(\$1.03/therm)) = 16.7years.

Monitoring and Evaluation

The evaluation portion of this project will be taken on a monthly basis by obtaining the Natural History Museum's PG&E bill. Any energy reducing systems that may have been installed will have an associated energy reduction which will be visible on the billing statement. The effectiveness of each measure can then be monitored by reviewing this billing statement. Plant Operations will be conducting the monitoring process for the duration of the operational lifetime of the system. In doing so, we are looking to confirm the findings of our analysis.

For the alternative of solar curtains or ceiling fan circulation the systems should be installed six months apart from each other. When the first is installed the PG&E bill should be monitored to find any savings. When the second is installed the PG&E bill should be monitored to find any savings.

Another method of monitoring would be by utilizing the DECK Monitoring. DECK Monitoring is a company that provides a hardware and web based software (Fig 1) system for solar arrays. For a one-time fee DECK Monitoring will calculate the kilowatts generated in real time for the life of the system. It also monitors the wind, temperature, and cloud coverage for any given hour. By using DECK Monitoring the HSU would quickly and easily be able to calculate the kilowatts generated by the solar array for each min, day, week, or year. The base Commercial package for a DECK Monitoring system for HSU would be $3,495 (Fig 2).

Fig 1

Fig 2

DECK Monitoring

Quote Name	HUMBOLDTSTATEUNIVERSITY112012ML NATURALHISTORYMUSEUM	Opportunity Name	Natural History Museum
		Expires	12/26/2012
Job Number	H7THSM		
Created Date	11/26/2012		
Prepared By	Mark Lammi	Account Name	Humboldt State University
Email	mark@deckmonitoring.com	Contact Name	David
Company Address	830 SW 10th Ave, Suite 200 Portland, OR 97205	Bill To	, CA

Product Code	Product	Product Description	List Price	Sales Price	Quantity	Total Price
CM5YP001	1.1 Commercial Solar Monitoring Equipment & Service Package	Includes (1) Preconfigured Revenue Grade Meter, 3 Phase, Modbus, (1) Communication Gateway, (1) 5 Year Monitoring Package with Public and Admin Panel Views. These products do NOT come with NEMA enclosures, please speak with your sales representative if needed	$3,495.00	$3,495.00	1.00	$3,495.00

Further Information: Acceptance of quote and or submittal of a PO based on this quote constitutes acceptance of DECK Monitoring terms viewable at: http://www.deckmonitoring.com/terms.pdf Please fill out the DECK site survey once a PO has been submitted. This is located at: http://www.deckmonitoring.com/site_survey/

Total Price: $3,495.00

Alternative Monitoring and Evaluation

HVAC

The monitoring and evaluation of the new HVAC system and ducting will be to monitor the PG&E bill versus the calculated savings.

Lighting

The monitoring and evaluation of the new LED lights will be to monitor the PG&E bill versus the calculated savings.

Air Circulation & Solar Curtains

Since it is very difficult to assign hard numbers to the possible benefits of circulating the warm air trapped in the high ceiling and how much heat could be retained from the installation of solar curtains we propose a six month monitoring plan. One alternative will be installed and the PG&E bill will be monitored for six months to find any savings. Then in the following year other alternative will be installed and the PG&E bill will be monitored for the same six months to find any savings

Discussion of Analysis

Solar Water - Although it will take approximately 16.7 years for the proposed solar thermal system to pay itself off, the energy saved must also be taken into consideration. Twelve years may seem like a long time but, given the fact that these systems can last up to 30 years, the return values are worth the trouble. Even though the system will take this long to repay itself, that will be 16.7 years that this building will be using the sun's energy to supply its hot water needs, as opposed to using natural gas. After this system has paid itself off, it will continue to run for an additional 13.3 years at least. Throughout this time period, the Natural History Museum will be directly saving the total cost of the amount of therms this system will replace.

Other Considerations

Embedded Energy of PV System:

Encompassed fossil fuel energy of a PV system, its dependence on finite resources, and other concerns must be looked at when considering the use of solar panels. Data was found by conducting a simple search. Information from before, during, and after the manufacturing process was compiled and assessed. From mining the resources from the Earth for manufacture, to recycling the product after its lifetime was considered in the evaluation. Looking at pollutants involved in the process will provide a better understanding for its cost on the environment. Understanding the maintenance will provide an understanding on the energy the user will have to put into the system to keep it efficient. Research will provide all data needed to better recognize the considerations involved when planning a PV solar array investment.

Solar power is a rising industry poised for explosive growth. It is a new and enticing technology for many who are looking to reduce their dependence on fossil fuels and who are looking for a cleaner alternative way to live. Since photovoltaic solar panels are new to the marketplace, their manufacturing and use have not yet been perfected. There are considerations one must consider and better understand before making the decision to go solar. Weighing out these considerations with cost benefit analysis and logical reasoning can help determine if solar is the right investment.

One of the benefits of PV panels is the freedom from dependence on finite resources, but manufacturing a PV panel requires an initial investment in finite resources and energy to produce. United States industry is dependent upon finite resources. Most industrial manufacturing processes use petroleum as their main energy source, natural gas and coal being subsequent sources. Data from the EIA in 2010 showed that 25% of the nation's energy came from petroleum, 22% from coal, and 22% from natural gas. Renewable energy only supplied 8% of the nation's energy (U.S. Department of Energy). Industry serves as a major exploitative force on our resources. PV panels need to be manufactured before they are able to be used and produce power. It takes power to make power. The processes in which PV panels are produced require an abundant amount of energy. From the mining of quartz sand to the coating with ethylene-vinyl acetate, manufacturing a photovoltaic solar cell requires energy, most often derived from the burning of fossil fuels. This is a dirty and energy intensive process similar to the manufacturing of computer chips. First, raw materials have to be mined: quartz sand for silicon cells, metal ore for thin film cells. Next, these materials have to be treated, following different steps (in the case of silicon cells these are purification, crystallization and wafering). Finally, these upgraded materials have to be manufactured into solar cells, and assembled into modules. All these processes produce air pollution and heavy metal emissions, and they consume energy which brings about more air pollution, heavy metal emissions and also greenhouse gases (Fthenakis, Kim & Alsema, 2008) Producing PV panels presents the opposite values of solar power production. It is calculated that one square meter of solar cells carries a burden of 75 kilograms of CO2 (Fthenakis, Kim & Alsema, 2008). Most homes, or businesses, require more than one square meter of panels to be beneficial, therefore the amount of carbon dioxide emissions associated with the manufacturing of these panels is multiplied by each square meter. This also does not take into consideration the transportation and installation carbon dioxide burden. Carbon dioxide is a main emission related to the manufacturing of PV panels, but others pollutants play a role as well. Pollutants such as nitrogen trifluoride and sulfur hexafluoride have been traced back to the production of solar panels. These are some of the most potent greenhouse gases with a thousand times more potent Global Warming Potential (GWP) than carbon dioxide. Nitrogen trifluoride is 17,200 times greater GWP than carbon dioxide, and sulfur hexafluoride is 22,800 times greater than carbon dioxide, which is the most potent greenhouse gas evaluated according to IPCC in 2008. This is an evident burden that manufacturing solar panels creates. Releasing carbon dioxide, sulfur hexafluoride, and nitrogen trifluoride into the atmosphere assists the acceleration of global climate change and air pollution. Although, once solar panels are produced and installed, they essentially have no emissions associated with them. So the problem lies in the manufacturing aspect of solar power. Looking at the larger picture, solar only makes up 1% of the nation's electrical market, meaning that although the manufacturing shows a large burden on the environment, it is small compared to other industrial energy manufacturing. Solar cells pay back the energy involved in their manufacture in one to three years. The most energy-intensive to produce, monocrystalline silicate cells, emits just .005 kilograms of global warming pollution per kilowatt hour, which is a far less fraction of the near 1 kilogram of global warming pollution emitted by a coal-fired power plant per kilowatt-hour (Biello, 2008). The embedded energy in the production of solar panels is relatively small, and has the capability of becoming more efficient.

Once PV systems are installed, concerns about greenhouse gas emissions are no longer important, but other problems may arise. The first and most obvious trouble that arises in the use of solar energy is that the sun doesn't shine for 24 hours a day. PV systems require sunlight to produce energy, and when the sun doesn't shine, the system will not produce energy. This is not problematic if your goal is to power your specified building for the duration of the day when there is sunlight. Most buildings, however, need power through the night. During sunlight hours, energy can be saved and stored for later use by using a battery. If you are off the grid, batteries are essential for power use through the night. If you are connected to the grid, then batteries are not required because you can tap into the electricity from the grid when you need power when the sun is not out. Batteries have a lifetime of about 6-12 years, which is at most half the lifetime of a PV panel. Replacement batteries will be required at least a few times and may become costly. If you are located in an area where it is often cloudy and rainy, the ability to obtain maximum power is far less than if you were in a region of constant sun for obvious reasons; a photovoltaic system requires sunlight. It is easy to find the amount of full sun hours a region has, you can find it by conducting simple research. Knowing a regions number of full sun hours, you can evaluate its efficiency and determine if the system will generate enough energy to benefit that system, or reach another desired goal.

Weathering is another concern to be measured. Solar panels have a 1-2% degrading factor per year depending on climatic conditions. Rain, dust, snow, and other weathering elements can affect the efficiency and degrading factor of the panel. Large amounts of weathering on a panel means that it will degrade faster than one not exposed to as much weathering. Cleaning is required at least once a year (Strecker, 2011). PV panels are very easy to clean and cleaning does not require hiring someone for the job, although you certainly can hire someone if that is your preference. The panels can simply be wiped down or hosed off for cleaning. If the panels are located on roofs, it may be a little more difficult to clean, and possible dangerous. It is important to judge the area before cleaning.

Once the panels have outlived their lifetime, they will need to be disposed of. PV panels are not your regular waste item, and must be disposed of properly and cannot just be thrown away. They can be recycled or reused to create new panels. But since solar currently only makes up 1% of the United States electricity market, it's a very minor new technology here in our country and there are not reliable recycling and disposal methods within policies of the industry. A lot of electronic waste ends up in developing countries where the residents burn out valuable materials, spilling contaminants into their water, air and lungs. This creates more problems if we do not recycle properly. More and more corporations are developing some sort of recycling program to deviate away from abundant electronic waste. There are several groups that are developing recycling programs, such as PV Cycle and Silicon Valley Toxics Coalition, which will collect the outlived panels (Dickerson, 2009). It is beneficial to talk to the manufacturers about policies regarding recycling before you consider purchasing PV panels, or look into other organization's policies to ensure that your panels will be disposed of properly.

Conclusion

After conducting a PV and cost analysis, it can be concluded that offsetting 100% of the energy purchased from PG&E from the use of a photovoltaic system is not feasible. Although the primary objective of this project was not met, the overall success of this project was substantial in regards to analyzing the natural history museums energy use. Unfortunately, it was determined that PV system cost was too great and therefore infeasible. However, this analysis has given a thorough foundation on which future projects and decisions can be based. This analysis has also given insight on areas where new work can be done to increase the feasibility of solar projects here at HSU. These areas include financing methods such as subsidies loans, solar leasing options, and alternative electricity rate options.

While the proposed solar array failed to make economic sense there were some successes in alternatives. We recommend that Humboldt State University installs the new proposed HVAC system and ducting. The current HVAC system is so degraded that a new system will effectively double its efficiency and half the amount of power purchased from PG&E that is currently used for heating. The installation of the new HVAC system and ducting would save the Natural History Museum $525.66 a year, with a buyback time of 11 years.

We recommend that Humboldt State University replace all T8 fluorescent bulbs with equivalent LED's. The replacement of the current bulbs would effectively half the amount of power purchased from PG&E that is currently used for lighting. LED bulbs would save the Natural History Museum $541.90 a year, with a buyback time of 9.88 years.

We recommend that Humboldt State University installs six ceiling fans in the main room of the Natural History Museum to circulate the hot air trapped in the large ceiling area. While we do not know the amount of savings this would provide the total cost of $300 is low enough to experiment.

Without knowing the possible small amount of saving the solar curtains could provide, and the aesthetic detriment it would bring to the entrance to the Natural History Museum, we do not recommend its installation.

The solar water heater alternative would not be a good alternative to spend resources and time in due to the small amount of hot water needed by the Natural History Museum, and because of the buyback time of 16.7 years on the initial investment of $2981.

Works Cited

Biello, D. (2008). Dark side of the solar cell brightness. *Scientific American*

California California Solar Initiative - Solar Water Heating Rebate Program. (n.d.). *DSIRE: Database of Energy Efficiency, Renewable Energy Solar Incentives, Rebates, Programs, Policy*. Retrieved December 7, 2012, from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA214F&re=0&ee=0

Cory, T. (2012, November 21). Telephone interview.

Database of state incentives for renewables and efficiency. (2011, December). Retrieved from http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=CA214F&re=0&ee=0

Edidson Electric Institute. (2008). Rising Electricity Costs: a Challenge for Consumers, Regulators, and Utilities. Retrieved November 22, 2012, from

http://www.eei.org/whatwedo/PublicPolicyAdvocacy/StateRegulation/Documents/rising_elect
city_costs.pdf

Fthenakis, V., Kim, H. & Alsema, E. (2008). Emissions from photovoltaic life cycles. *Environmental Science Technology*, 2168-2174
Heat your water with the sun. (2003). Retrieved from http://www.nrel.gov/docs/fy04osti/34279.pdf

Hinchcliff, T. (2012, November 20). Email interview.

Industrial 56 in. Brushed Nickel Ceiling Fan-7861400 at The Home Depot. (n.d.).*Home Improvement Made Easy with New Lower Prices | Improve & Repair*. Retrieved December 6, 2012, from http://www.homedepot.com/webapp/wcs/stores/servlet/ProductDisplay?productId=202759709&storeId=10051&langId=-1&catalogId=10053&ci_sku=202759709&ci_kw=%7bkeyword%7d&kwd=%7bkeyword%7d&cm_mmc=shopping%2d%5f%2dgoogleads%2d%5f%2dpla%2d%5f%2d202759709&ci_gpa=pla

IPCC. (2008). Climate change 2007. *The Physical Sciences Basis*

LED Bulb- T8 - 50,000 Hour Life - 10 Watts - 2 Foot replacement or upgrade for fluorescent light fixtures - MagnaLight . (n.d.). *Magnalight Golight, Explosion proof lights, Magnetic Spotlight, 24 volt & 12v Military Spotlights, HID & LED lights, Remote Control*. Retrieved

December 6, 2012, from http://www.magnalight.com/p-48514-led-bulb-t8-8-watts-2-foot-replacement-or-upgrade-for-fluorescent-light-fixtures-.aspx

Marla, D. (2009). Solar energy's darker side turns concern. *Los Angeles Times* Navigant Consulting Inc. (2006).*A Review of PV Inverter Technology Cost and Performance Projections*. Retrieved November 22, 2012, from http://www.nrel.gov/docs/fy06osti/38771.pdf

PowerReviews. (n.d.). Solar Curtain | Miscellaneous | Housewares . *AmeriMark Online Shopping*. Retrieved December 6, 2012, from http://www.amerimark.com/cgi-bin/amerimark/esearch.html?keywords=023212&media=2GOOG22A&days=XVQ&cm_mmc=PaidSearch-_-GooglePLA-_-199ship-_-02321202000&gclid=COvmxOWnh7QCFQ45nAodik4AKw

PVWatts calculator. (2012) *National Renewable Energy Laboratory*. n.d. Retrieved From: http://www.nrel.gov/rredc/pvwatts/changing_parameters.html#dc_rating

Solar Collector Sizing Solar Hot Water Heater Manufacturer. Solar Hot Water Manufacturer & Distributor. Silicon Solar, n.d. Web. 7 Dec. 2012. http://solarhotwater.siliconsolar.com/solar-collector-sizing.html

Solar Collector Sizing | Solar Hot Water Heater Manufacturer. (n.d.). *Solar Hot Water Manufacturer & Distributor*. Retrieved December 7, 2012, from http://solarhotwater.siliconsolar.com/solar-collector-sizing.html

Solar Design Group. (n.d.). *Solar Advantages*. Retrieved October 28, 2012, from www.solardesigngroupllc.com/overview.html

Solar Thermal Costs, Paybacks and Maintenance. (n.d.). *Welcome | Southface*. Retrieved December 7, 2012, from http://www.southface.org/learning-center/library/solar-resources/solar-thermal-costs-paybacks-and-maintenance

Solar thermal costs and maintenance. (2012). Retrieved from http://www.southface.org/learning-center/library/solar-resources/solar-thermal-costs-paybacks-and-maintenance

Solar Water Heaters | Department of Energy. (n.d.). *Energy.gov | Department of Energy*. Retrieved December 7, 2012, from http://energy.gov/energysaver/articles/solar-water-heaters

Statewide Trigger Point Tracker. (2012). *Go Solar California* . Retrieved November 22, 2012, from http://www.csi-trigger.com/

Strecker, R. (2011). Solar panels lifetime productivity and maintenance costs. *Boston Solar*

The World Bank (2011).*Real Interest Rate (%)*. Retrieved November 22, 2012, from http://data.worldbank.org/indicator/FR.INR.RINR

Trendsetter Solar Water Heating System Sizing. (n.d.). *Solar Direct*. Retrieved December 7, 2012, from http://www.solardirect.com/water-heaters/solar/active/trendsetter/sizing.htm

Ultra8 T8 - Fluorescent - General Lighting - USHIO. (n.d.). *USHIO manufacture and distribute a broad range of Halogen, Xenon, Fluorescent, EmArc Enhanced Metal Arc, Metal Halide, Mercury, Incandescent, Specialty PAR, Sodium, Quartz-Infrared Heater and Miniature lamps.*. Retrieved December 6, 2012, from http://www.ushio.com/products/generallighting/f-ultra8t8.htm

US Dept. of Energy, "Annual Energy Report" (2010), Energy Flow diagram

Appendix A

HSU Natural History Museum

Electricity Usage

current_read_date	num_days	e_or_g	rate	Total Usage (kWh)	Electric Charges	$/kwh
August-12	29	E	A1	1953	$230.19	$0.118
July-12	32	E	A1	1905	$225.81	$0.119
June-12	30	E	A1	1959	$231.29	$0.118
May-12	30	E	A1	2041	$213.84	$0.105
April-12	31	E	A1	2140	$192.04	$0.090
March-12	30	E	A1	2458	$218.00	$0.089
February-12	29	E	A1	2554	$224.92	$0.088
January-12	33	E	A1	2447	$215.70	$0.088
December-11	29	E	A1	1921	$169.00	$0.088
November-11	30	E	A1	1953	$191.50	$0.098
October-11	31	E	A1	1810	$199.06	$0.110
September-11	30	E	A1	1740	$191.42	$0.110
August-11	29	E	A1	1705	$187.47	$0.110
July-11	32	E	A1	1818	$200.18	$0.110
June-11	30	E	A1	1820	$199.82	$0.110
May-11	29	E	A1	1782	$181.07	$0.102
April-11	31	E	A1	1986	$175.01	$0.088
March-11	31	E	A1	2156	$187.77	$0.087
February-11	29	E	A1	1991	$171.40	$0.086
January-11	32	E	A1	2080	$170.21	$0.082
December-10	30	E	A1	1855	$141.53	$0.076
November-10	30	E	A1	1945	$165.07	$0.085
October-10	31	E	A1	1866	$180.48	$0.097
September-10	30	E	A1	1120	$111.70	$0.100
August-10	30	E	A1	779	$80.38	$0.103
July-10	32	E	A1	953	$96.93	$0.102
June-10	30	E	A1	837	$87.73	$0.105
May-10	29	E	A1	887	$87.93	$0.099
April-10	31	E	A1	1167	$98.39	$0.084
March-10	30	E	A1	1201	$99.27	$0.083
February-10	33	E	A1	1381	$110.85	$0.080
January-10	30	E	A1	1228	$91.48	$0.074
December-09	30	E	A1	1345	$91.35	$0.068
November-09	32	E	A1	1617	$124.07	$0.077
October-09	29	E	A1	1527	$131.06	$0.086
September-09	30	E	A1	1922	$162.69	$0.085
August-09	31	E	A1	2819	$234.75	$0.083
July-09	31	E	A1	2805	$233.63	$0.083
June-09	29	E	A1	2668	$222.06	$0.083
May-09	31	E	A1	3030	$227.37	$0.075
April-09	30	E	A1	2979	$190.41	$0.064
March-09	29	E	A1	3122	$196.65	$0.063
February-09	33	E	A1	3658	$225.94	$0.062
January-09	30	E	A1	2892	$186.11	$0.064
December-08	32	E	A1	3448	$228.26	$0.066
November-08	30	E	A1	3282	$249.08	$0.076
October-08	29	E	A1	2970	$251.28	$0.085
September-08	32	E	A1	2681	$228.54	$0.085
August-08	29	E	A1	2889	$244.64	$0.085
July-08	30	E	A1	2741	$232.84	$0.085
June-08	33	E	A1	3000	$254.89	$0.085
May-08	28	E	A1	2813	$214.13	$0.076
April-08	30	E	A1	3184	$210.55	$0.066
March-08	31	E	A1	3377	$221.88	$0.066
February-08	31	E	A1	3664	$238.20	$0.065
January-08	29	E	A1	3326	$228.75	$0.069
December-07	32	E	A1	3367	$247.58	$0.074
November-07	29	E	A1	3112	$258.20	$0.083
October-07	29	E	A1	2943	$278.95	$0.095
September-07	31	E	A1	2680	$255.23	$0.095
August-07	29	E	A1	2785	$264.38	$0.095
July-07	31	E	A1	2857	$271.56	$0.095
June-07	33	E	A1	3135	$297.67	$0.095
May-07	28	E	A1	2985	$260.45	$0.087
April-07	30	E	A1	3314	$244.73	$0.074
March-07	29	E	A1	3365	$249.13	$0.074
February-07	32	E	A1	3855	$288.09	$0.075
January-07	31	E	A1	3555	$268.15	$0.075

PV Cost Analysis

System Size: 24kW

Installed cost of system: $95,350.00

Sales tax: 9% sales tax rate in Arcata Tax on system = $8,581.50

2. After-tax cost of system: $103,931.50

3. Rebates and tax credits:

Available rebate was found using the 2012 California Solar Initiative rebate per Watt using step 10 of the EPBB residential table at http://www.csi-trigger.com/

CSI rebate per Watt 2012 for gov/nonprofit: $0.70 Total rebate, 24 kW system = $16,800.00

The net up-front cost of installed system after the CSI rebate = total cost - rebate.

Net up-front cost of installed system = $87,131.50

Sources cited

Cory, T. (2012, November 21). Telephone interview.

Edidson Electric Institute. (2008). Rising Electricity Costs: a Challenge for Consumers, Regulators, and Utilities. Retrieved November 22, 2012, from http://www.eei.org/whatwedo/PublicPolicyAdvocacy/StateRegulation/Documents/rising_electricity_costs.pdf

Hinchcliff, T. (2012, November 20). Email interview.

Navigant Consulting Inc. (2006). *A Review of PV Inverter Technology Cost and Performance Projections.* Retrieved November 22, 2012, from http://www.nrel.gov/docs/fy06osti/38771.pdf

Statewide Trigger Point Tracker. (2012, November 2). *Go Solar California* . Retrieved November 22, 2012, from http://www.csi-trigger.com/

The World Bank (2011). *Real Interest Rate (%).* Retrieved November 22, 2012, from http://data.worldbank.org/indicator/FR.INR.RINR

Lifecycle Cost Analysis and Levelized Cost of Energy

Recurring costs

Inverters for a 24 kW system have a 10 year warranty, and currently cost $9,026. We assume that inverter costs will decline by 2% per year in real terms, consistent with a study by Navigant consulting (2006) for the National Renewable Energy Laboratory. We will also assume real maintenance cost of $100/year.

Interest rates :

Definition: The "real" interest rate (discount rate) is the underlying rate of interest after the overall inflation rate is subtracted. For example, if the real interest rate is 2% and inflation is 3%, then the nominal interest rate is 5%. We will do all our analysis using real discount rates. Doing so will allow us to leave out inflation from our analysis. The real interest rate reflects the underlying time value of money.

The future cost of inverter replacement:

$$FV = PV \cdot (1 + i)^n$$

Where "i" is the interest rate and "n" is the number of periods from now until the future period.

If "rate" = -0.02 and "j" is 10 years, future real cost of the first inverter replacement will be: **$7,374.90**

If "rate" = -0.02 and "j" is 20 years, the future real cost of the second inverter replacement will be: **$6,025.83**

Cost table

Year	Real Costs (in constant 2012 dollars)
0	**$87,131.50**
1	**$100.00**
2	**$100.00**
3	**$100.00**
4	**$100.00**
5	**$100.00**
6	**$100.00**
7	**$100.00**
8	**$100.00**
9	**$100.00**
10	**$7,374.90**
11	**$100.00**
12	**$100.00**
13	**$100.00**
14	**$100.00**
15	**$100.00**
16	**$100.00**
17	**$100.00**
18	**$100.00**
19	**$100.00**
20	**$6,025.83**
21	**$100.00**
22	**$100.00**
23	**$100.00**
24	**$100.00**
25	**$100.00**

Present value of a future sum:

$$NPV = \sum_{j=1}^{n} \frac{values_j}{(1+rate)^j}$$

Where "rate" is the interest rate and "j" is the number of periods from now (period 0) until the end of the equipment's life (25).

Total lifecycle cost calculated by applying the NPV formula above to each cost, and suming them.

Assuming the real interest rate is .5%, calculate total lifecycle cost.

Lifecycle cost = **$101,760.27** In constant current dollars.

Calculating present value of lifetime energy production

NREL's PV-WATTS calculator was used at http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

Arcata, California : A 24 kW system will generate **28777.00** kilowatt hours per year of AC energy in its first year of operation.

To account for system degradation over time it is assumed that total AC kilowatt hours per year declines at 0.8% per year (20%/25years) after the first year, calculate annual energy production for 25 years:

Year	kWh AC Energy Total	kWh AC Energy Usable
1	**28777.00**	**22762.00**
2	**28546.78**	**22579.90**
3	**28318.41**	**22399.26**
4	**28091.86**	**22220.07**
5	**27867.13**	**22042.31**
6	**27644.19**	**21865.97**
7	**27423.04**	**21691.04**
8	**27203.65**	**21517.52**
9	**26986.02**	**21345.38**
10	**26770.14**	**21174.61**
11	**26555.97**	**21005.22**
12	**26343.53**	**20837.17**
13	**26132.78**	**20670.48**
14	**25923.72**	**20505.11**
15	**25716.33**	**20341.07**
16	**25510.60**	**20178.34**
17	**25306.51**	**20016.92**
18	**25104.06**	**19856.78**
19	**24903.23**	**19697.93**
20	**24704.00**	**19540.34**
21	**24506.37**	**19384.02**
22	**24310.32**	**19228.95**
23	**24115.84**	**19075.12**
24	**23922.91**	**18922.52**
25	**23731.53**	**18771.14**

PV lifecycle energy production: (Total) **654,415.89**
(Usable) **517,629.17** kilowatt hours

Levelized cost of energy (LCOE)

LCOE = (Total) **$0.1555** /kWh (Actual) **$0.1966** /kWh

Avoided Cost of Electricity

Below Values are for January Through December of 2011

Average monthly kWh	Average Cost $/kWh	Cumulative KWh	Total Cost $
1896.83	0.098	**22762**	**2223.91**

Annual Avoided Energy Costs, 2011: **$2,223.91**

Real energy price escalation

Forecast of the annual avoided energy costs for the next 25 years (the assumed life of the PV system).
For lighting and appliances, we will assume that the pattern of annual avoided energy consumption remains constant over time.
Thus the only issue we need to address is real energy price escalation for avoided electricity from PG&E.
For our purposes, we will assume that PG&E's electricity rates will grow .5% faster than underlying inflation.

Lifecycle private benefits (avoided real energy costs)

Year	Avoided Real Energy Costs
1	**$2,223.91**
2	**$2,235.03**
3	**$2,246.20**
4	**$2,257.44**
5	**$2,268.72**
6	**$2,280.07**
7	**$2,291.47**
8	**$2,302.92**
9	**$2,314.44**
10	**$2,326.01**
11	**$2,337.64**
12	**$2,349.33**
13	**$2,361.08**
14	**$2,372.88**
15	**$2,384.75**
16	**$2,396.67**
17	**$2,408.65**
18	**$2,420.70**
19	**$2,432.80**
20	**$2,444.96**
21	**$2,457.19**
22	**$2,469.47**
23	**$2,481.82**
24	**$2,494.23**
25	**$2,506.70**

Lifecycle private benefits (avoided real energy costs) = (NPV) = **$55,321.14**

Calculating NPV and IRR

Net real cash flow table

Year	A Real Costs	B Real Benefits (avoided costs)	Net Real Cash Flow
0	$87,132	$0	**-$87,132**
1	$100	$2,224	**$2,124**
2	$100	$2,235	**$2,135**
3	$100	$2,246	**$2,146**
4	$100	$2,257	**$2,157**
5	$100	$2,269	**$2,169**
6	$100	$2,280	**$2,180**
7	$100	$2,291	**$2,191**
8	$100	$2,303	**$2,203**
9	$100	$2,314	**$2,214**
10	$7,375	$2,326	**-$5,049**
11	$100	$2,338	**$2,238**
12	$100	$2,349	**$2,249**
13	$100	$2,361	**$2,261**
14	$100	$2,373	**$2,273**
15	$100	$2,385	**$2,285**
16	$100	$2,397	**$2,297**
17	$100	$2,409	**$2,309**
18	$100	$2,421	**$2,321**
19	$100	$2,433	**$2,333**
20	$6,026	$2,445	**-$3,581**
21	$100	$2,457	**$2,357**
22	$100	$2,469	**$2,369**
23	$100	$2,482	**$2,382**
24	$100	$2,494	**$2,394**
25	$100	$2,507	**$2,407**

NPV calculations

IRR: **-5%**

Net present value (NPV) of the net real cash flow for a .5%, 3%, and 5% assumed real rate of return to finance the project.

NPV 0.5%	**-$46,439.13**
NPV 3%	**-$56,738.65**
NPV 5%	**-$62,352.15**

Simple and Discounted Payback Period

Year	Real Costs	Real Benefits (avoided costs)	Net Annual Cash Flow	Discounted Net Annual Cash Flow @.5%	Undiscounted Accumulated Net Cash Flow	Discounted Accumulated Net Cash Flow @ .5%
0	$87,132	$0	-$87,132	-$87,131.50	$0.00	$0.00
1	$100	$2,224	$2,124	$2,113.34	-$85,007.59	-$85,018.16
2	$100	$2,235	$2,135	$2,113.84	-$82,872.56	-$82,904.32
3	$100	$2,246	$2,146	$2,114.33	-$80,726.36	-$80,789.99
4	$100	$2,257	$2,157	$2,114.82	-$78,568.92	-$78,675.17
5	$100	$2,269	$2,169	$2,115.31	-$76,400.20	-$76,559.86
6	$100	$2,280	$2,180	$2,115.79	-$74,220.13	-$74,444.06
7	$100	$2,291	$2,191	$2,116.28	-$72,028.66	-$72,327.79
8	$100	$2,303	$2,203	$2,116.76	-$69,825.74	-$70,211.03
9	$100	$2,314	$2,214	$2,117.24	-$67,611.30	-$68,093.79
10	$7,375	$2,326	-$5,049	-$4,803.25	-$72,660.19	-$72,897.04
11	$100	$2,338	$2,238	$2,118.18	-$70,422.55	-$70,778.86
12	$100	$2,349	$2,249	$2,118.66	-$68,173.22	-$68,660.20
13	$100	$2,361	$2,261	$2,119.12	-$65,912.14	-$66,541.08
14	$100	$2,373	$2,273	$2,119.59	-$63,639.26	-$64,421.49
15	$100	$2,385	$2,285	$2,120.05	-$61,354.52	-$62,301.44
16	$100	$2,397	$2,297	$2,120.52	-$59,057.85	-$60,180.92
17	$100	$2,409	$2,309	$2,120.98	-$56,749.19	-$58,059.95
18	$100	$2,421	$2,321	$2,121.43	-$54,428.50	-$55,938.51
19	$100	$2,433	$2,333	$2,121.89	-$52,095.70	-$53,816.63
20	$6,026	$2,445	-$3,581	-$3,240.91	-$55,676.56	-$57,057.54
21	$100	$2,457	$2,357	$2,122.79	-$53,319.38	-$54,934.75
22	$100	$2,469	$2,369	$2,123.24	-$50,949.90	-$52,811.51
23	$100	$2,482	$2,382	$2,123.68	-$48,568.08	-$50,687.82
24	$100	$2,494	$2,394	$2,124.13	-$46,173.85	-$48,563.70
25	$100	$2,507	$2,407	$2,124.57	-$43,767.15	-$46,439.13

*Running Balance at the end of the system lifetime indticates that the project will not pay for itself withen the 25 years of its warrenty coverage.

PV Cost Analysis

System Size: 12.25kW

Installed cost of system: **$42,515.00**

Sales tax: 9% sales tax rate in Arcata Tax on system = **$3,826.35**

2. After-tax cost of system: **$46,341.35**

3. Rebates and tax credits:

Available rebate was found using the 2012 California Solar Initiative rebate per Watt using step 10 of the EPBB residential table at http://www.csi-trigger.com/

CSI rebate per Watt 2012 for gov/nonprofit: **$0.70** Total rebate, 24 kW system = **$8,575.00**

The net up-front cost of installed system after the CSI rebate = total cost - rebate.

Net up-front cost of installed system = **$37,766.35**

Sources cited

Cory, T. (2012, November 21). Telephone interview.

Edidson Electric Institute. (2008). Rising Electricity Costs: a Challenge for Consumers, Regulators, and Utilities. Retrieved November 22, 2012, from http://www.eei.org/whatwedo/PublicPolicyAdvocacy/StateRegulation/Documents/rising_electricity_costs.pdf

Hinchcliff, T. (2012, November 20). Email interview.

Navigant Consulting Inc. (2006). *A Review of PV Inverter Technology Cost and Performance Projections*. Retrieved November 22, 2012, from http://www.nrel.gov/docs/fy06osti/38771.pdf

Statewide Trigger Point Tracker. (2012, November 2). *Go Solar California* . Retrieved November 22, 2012, from http://www.csi-trigger.com/

The World Bank (2011). *Real Interest Rate (%)*. Retrieved November 22, 2012, from http://data.worldbank.org/indicator/FR.INR.RINR

Lifecycle Cost Analysis and Levelized Cost of Energy

Recurring costs

Inverters for a 12.25 kW system have a 10 year warrantee, and currently cost $4,513. We assume that inverter costs will decline by 2% per year in real terms, consistent with a study by Navigant consulting (2006) for the National Renewable Energy Laboratory. We will also assume real maintenance cost of $100/year.

Interest rates :

Definition: The "real" interest rate (discount rate) is the underlying rate of interest after the overall inflation rate is subtracted. For example, if the nominal interest rate is 5% and inflation is 3%, then the real interest rate is 2%. This analysis is done using real discount rates. Doing so will allow us to leave out inflation from our analysis. The real interest rate reflects the underlying time value of money.

The future cost of inverter replacement:

$$FV = PV \cdot (1 + i)^n$$

Where "i" is the interest rate and "n" is the number of periods from now until the future period.

If "rate" = -0.02 and "j" is 10 years, future real cost of the first inverter replacement will be: $3,687.45

If "rate" = -0.02 and "j" is 20 years, future real cost of the secound inverter replacement will be: $3,012.91

Cost table

Year	Real Costs (in constant 2012 dollars)
0	$37,766.35
1	$100.00
2	$100.00
3	$100.00
4	$100.00
5	$100.00
6	$100.00
7	$100.00
8	$100.00
9	$100.00
10	$3,687.45
11	$100.00
12	$100.00
13	$100.00
14	$100.00
15	$100.00
16	$100.00
17	$100.00
18	$100.00
19	$100.00
20	$3,012.91
21	$100.00
22	$100.00
23	$100.00
24	$100.00
25	$100.00

Present value of a future sum:

$$NPV = \sum_{j=1}^{n} \frac{values_j}{(1 + rate)^j}$$

Where "rate" is the interest rate and "j" is the number of periods from now (period 0) until the end of the equipment's life (25).

Total lifecycle cost calculated by applying the PV formula above to each cost, and suming them.

Assuming the real interest rate is 0.5%, calculate total lifecycle cost.

Lifecycle cost = **$46,160.20** In constant current dollars.

Calculating present value of lifetime energy production

NREL's PV-WATTS calculator was used at http://rredc.nrel.gov/solar/codes_algs/PVWATTS/version1/

Arcata, California : A 12.25 kW system will generate **$14,688.00** kilowatt hours per year of AC energy in its first year of operation.

To account for system degradation over time it is assumed that total AC kilowatt hours per year declines at 0.8% per year (20%/25years) after the first year, calculate annual energy production for 25 years:

Year	kWh AC Energy
1	**14688.00**
2	**14570.50**
3	**14453.93**
4	**14338.30**
5	**14223.59**
6	**14109.81**
7	**13996.93**
8	**13884.95**
9	**13773.87**
10	**13663.68**
11	**13554.37**
12	**13445.94**
13	**13338.37**
14	**13231.66**
15	**13125.81**
16	**13020.80**
17	**12916.64**
18	**12813.30**
19	**12710.80**
20	**12609.11**
21	**12508.24**
22	**12408.17**
23	**12308.91**
24	**12210.43**
25	**12112.75**

PV lifecycle energy production: **334,018.86** kilowatt hours

Levelized cost of energy (LCOE)

LCOE = **$0.1382**

Avoided Cost of Electricity

Average monthly kWh	Average Cost $/kWh	Cumulative KWh/Mo	Total Cost $
1896.83	**0.098**	**22762**	**2223.91**

Avodied KWH/Year:	**14688**	Avoided Cost/year $	**1439.424**

Annual Avoided Energy Costs, 2011:

Real energy price escalation

Forecast of the annual avoided energy costs for the next 25 years (the assumed life of the PV system).
For lighting and appliances, we will assume that the pattern of annual avoided energy consumption remains constant over time.
Thus the only issue we need to address is real energy price escalation for avoided electricity from PG&E.
For our purposes, we will assume that PG&E's electricity rates will grow .5% faster than underlying inflation.

Lifecycle private benefits (avoided real energy costs)

Year	Avoided Real Energy Costs
1	**$1,439.42**
2	**$1,440.14**
3	**$1,440.86**
4	**$1,441.58**
5	**$1,442.31**
6	**$1,443.03**
7	**$1,443.75**
8	**$1,444.47**
9	**$1,445.19**
10	**$1,445.91**
11	**$1,446.64**
12	**$1,447.36**
13	**$1,448.08**
14	**$1,448.81**
15	**$1,449.53**
16	**$1,450.26**
17	**$1,450.98**
18	**$1,451.71**
19	**$1,452.43**
20	**$1,453.16**
21	**$1,453.89**
22	**$1,454.61**
23	**$1,455.34**
24	**$1,456.07**
25	**$1,456.80**

Lifecycle private benefits (avoided real energy costs) = (NPV) = **$33,947.08**

Calculating NPV and IRR

Net real cash flow table

Year	A Real Costs	B Real Benefits (avoided costs)	Net Real Cash Flow
0	$37,766	$0	**-$37,766**
1	$100	$1,439	**$1,339**
2	$100	$1,440	**$1,340**
3	$100	$1,441	**$1,341**
4	$100	$1,442	**$1,342**
5	$100	$1,442	**$1,342**
6	$100	$1,443	**$1,343**
7	$100	$1,444	**$1,344**
8	$100	$1,444	**$1,344**
9	$100	$1,445	**$1,345**
10	$3,687	$1,446	**-$2,242**
11	$100	$1,447	**$1,347**
12	$100	$1,447	**$1,347**
13	$100	$1,448	**$1,348**
14	$100	$1,449	**$1,349**
15	$100	$1,450	**$1,350**
16	$100	$1,450	**$1,350**
17	$100	$1,451	**$1,351**
18	$100	$1,452	**$1,352**
19	$100	$1,452	**$1,352**
20	$3,013	$1,453	**-$1,560**
21	$100	$1,454	**$1,354**
22	$100	$1,455	**$1,355**
23	$100	$1,455	**$1,355**
24	$100	$1,456	**$1,356**
25	$100	$1,457	**$1,357**

NPV calculations

IRR: **-2%**

Net present value (NPV) of the net real cash flow for a .5%, 3%, and 5% assumed real rate of return to finance the project.

NPV 0.5%	**-$12,213.12**
NPV 3%	**-$18,593.20**
NPV 5%	**-$18,593.20**

Simple and Discounted Payback Period

Year	Real Costs	Real Benefits (avoided costs)	Net Annual Cash Flow	Discounted Net Annual Cash Flow @.5%	Undiscounted Accumulated Net Cash Flow	Discounted Accumulated Net Cash Flow @ .5%
0	$37,766	$0	-$37,766.35	-$37,766.35	$0.00	$0.00
1	$100	$1,439	$1,339.42	$1,338.75	-$36,426.93	-$36,427.60
2	$100	$1,440	$1,340.14	$1,338.80	-$35,086.78	-$35,088.79
3	$100	$1,441	$1,340.86	$1,338.85	-$33,745.92	-$33,749.94
4	$100	$1,442	$1,341.58	$1,338.90	-$32,404.33	-$32,411.03
5	$100	$1,442	$1,342.31	$1,338.95	-$31,062.03	-$31,072.08
6	$100	$1,443	$1,343.03	$1,339.00	-$29,719.00	-$29,733.07
7	$100	$1,444	$1,343.75	$1,339.05	-$28,375.26	-$28,394.02
8	$100	$1,444	$1,344.47	$1,339.10	-$27,030.79	-$27,054.92
9	$100	$1,445	$1,345.19	$1,339.15	-$25,685.59	-$25,715.76
10	$3,687	$1,446	-$2,241.54	-$2,230.36	-$27,927.13	-$27,946.12
11	$100	$1,447	$1,346.64	$1,339.25	-$26,580.49	-$26,606.87
12	$100	$1,447	$1,347.36	$1,339.30	-$25,233.13	-$25,267.56
13	$100	$1,448	$1,348.08	$1,339.35	-$23,885.05	-$23,928.21
14	$100	$1,449	$1,348.81	$1,339.40	-$22,536.24	-$22,588.81
15	$100	$1,450	$1,349.53	$1,339.45	-$21,186.71	-$21,249.36
16	$100	$1,450	$1,350.26	$1,339.50	-$19,836.45	-$19,909.86
17	$100	$1,451	$1,350.98	$1,339.55	-$18,485.47	-$18,570.31
18	$100	$1,452	$1,351.71	$1,339.60	-$17,133.76	-$17,230.71
19	$100	$1,452	$1,352.43	$1,339.65	-$15,781.32	-$15,891.06
20	$3,013	$1,453	-$1,559.75	-$1,544.24	-$17,341.08	-$17,435.29
21	$100	$1,454	$1,353.89	$1,339.75	-$15,987.19	-$16,095.55
22	$100	$1,455	$1,354.61	$1,339.80	-$14,632.58	-$14,755.75
23	$100	$1,455	$1,355.34	$1,339.85	-$13,277.24	-$13,415.90
24	$100	$1,456	$1,356.07	$1,339.90	-$11,921.17	-$12,076.00
25	$100	$1,457	$1,356.80	$1,339.95	-$10,564.37	-$10,736.06

*Running Balance at the end of the system lifetime indticates that the project will not pay for itself wither the 25 years of its warrenty coverage.