Powering UCSC with a Solar Panel Farm

Dylan Moon EE180J
Aristotle Daphnis EE180J
Ricardo Salcedo EE180J
John Shokohi EE80J

Table of Contents

Abstract……………………………………………………………………………………..….3

History/Overview……………………………………………………………………………3

Introduction………………………………………………………………………..…...4

Inputs………………………………………………………………………….……..6

Analysis………………………………………………………………………….….8

Recommended Technologies……………………………………………………….…...10

Strategies………………………………………………………………………….…..17

Timeline/Costs…………………………………………………………………………...18

Regulation…………………………………………………………………………………..19

Work Contributions……………………………………………………………………...20

References……………………………………………………………………….…21

Abstract:

Solar power in California has been growing rapidly due to advanced efforts to promote energy production from renewable sources, and a Renewable Portfolio Standard (which requires that 20% of California's electricity come from renewable resources by 2010, and 33% by 2020). With California leading the nation in developing solar energy facilities, much of this power is expected to come from solar power. By the end of 2012, California had 364 MW of concentrated solar power and 2,559 MW of photovoltaics installed state-wide. Our purpose is to create a smart grid for the University of California, Santa Cruz. We plan to do this by creating a solar panel farm located in Monterey, California at the UC MBEST center, 47 miles from the UCSC campus.

History/Overview:

Back in 1994, the UC Regents purchased 1,084 acres of land that once was apart of the former Fort Ord military base. A big reason why the University of California spent $15,000,000 for such an investment was due to the persistent requests from elected representatives for the reuse of the old fort, and there they constructed UC MBEST (Monterey Bay Education, Science, and Technology center of the University of California), which is located just off the coast of Monterey Bay. This center was established in aim of creating a new Silicon Valley, where institutions and companies throughout the Central Coast region could collaborate their knowledge and formulate unique ideas. It is a regional economic development that was initially planned to provide an attractive environment for businesses in knowledge-related industries by fostering employment opportunities. UC MBEST was not created to be a teaching campus, but rather an interface between industries, government agencies, and UC's in order to facilitate the transfer of information via research programs and various evolving relationships. Originally, this extension of the UC system was expected to generate 3,000-4,000 jobs. However, no major corporations ever really established any branches at UC MBEST and by 2010, there was no sign of any significant progress being made and a strong network had yet to be established. Ever since the epiphany dawned on UC officials that the little amount of progress being made was failing to meet their initial expectations, the UC system has considered selling the parcel multiple times to the highest bidder in order to get a chunk of their money back. However, due to the facts that the land has yet to be purchased and much of the available land is not being utilized, our team is proposing the installation of a solar panel farm at UC MBEST able to provide UCSC's energy requirements indefinitely.

It is important to note that of the 1,084 acres of land owned by the University of California, about 600 of those acres include some of the region's richest biological resources and provide valuable ecosystem services. Due to the importance of this area, it has been incorporated into the UC Natural Reserve System, which is a network of natural areas that are protected throughout California. This leaves roughly 500 acres of land to be utilized for research and development. Of those 500 acres, only 50 acres of land will be required by our solar panel farm to power the UCSC campus.

Introduction:

Our goal is to power the University of California with a renewable energy source, specifically solar panels. Upon summing the annual electricity usage of each individual building and facility on the UCSC campus, we arrived at a figure of approximately 41,160,388 kWh in total energy expenditure for the year 2012. In order to ensure we don't fail to meet the energy requirements of the UCSC campus, we will aim to provide enough energy on our solar farm to match an amount upwards of 42,000,000 kWh.

Since 1996, UCSC has participated as a "Direct Access" customer with PG&E. PG&E operates under a standard Tiered Base Plan, with their Tier 1 pricing per kWh currently being 13 cents. Assuming UCSC does its best to conserve as much energy as possible monthly so that PG&E will not feel compelled to bump the bill up to the next, higher priced tier, we can estimate that our school pays roughly $5,330,000 per year on electricity. Since all of the energy that we are receiving from PG&E is obviously not renewable, we feel the need to propose a solution. PG&E's energy source distribution is as follows: 59% hydroelectric, 34% nuclear, 2% fossil fuels, but only 5% solar. By creating a solar panel farm at the UC MBEST site, we hope to tilt this distribution in a more favorable and sustainable direction by increasing the amount of renewable energy available to be utilized by the UCSC campus.

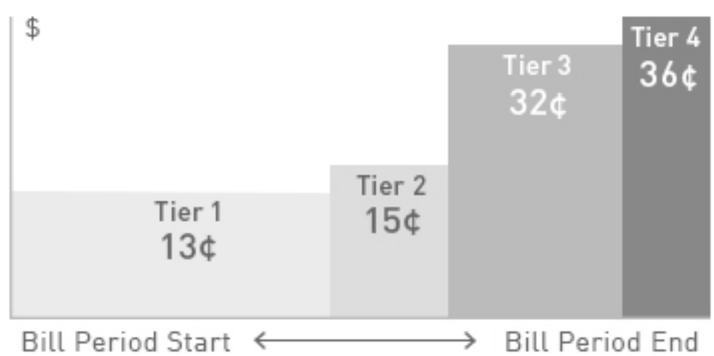

Figure 1: PG&E Standard Rate Plan

Through explicit calculations and explanations we will prove that creating a smart grid will benefit the University of California, Santa Cruz in various aspects. We will aim to create a realistic financial budget as well as a realistic energy budget. We will be working from worst case; working from worst case ensures us that our design will always be operational under any condition.

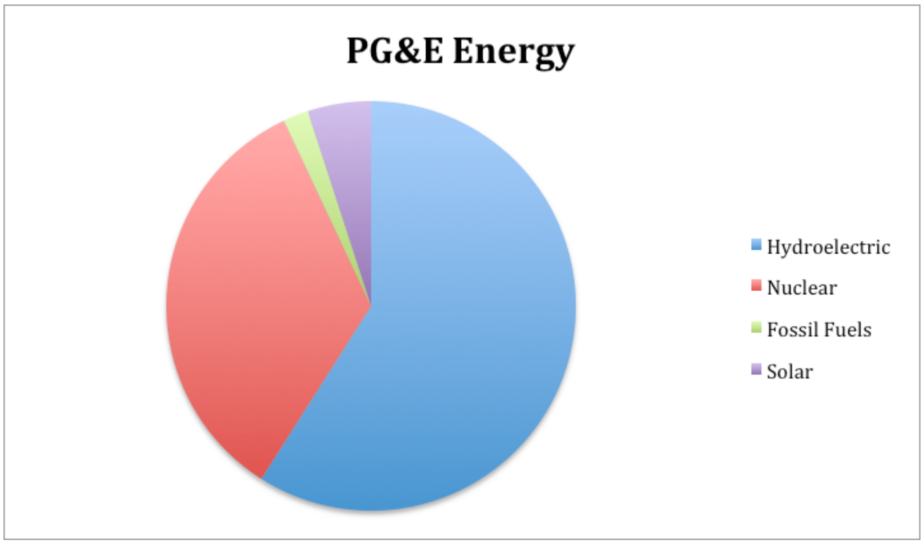

Figure 2: PG&E Energy Source Distribution Chart

Inputs:

Looking at the 2012 energy expenditure list given to us in class, we summed up all of the energy that each building and facility consumed on the UCSC campus during that year and got the total annual energy consumption to be approximately 41,160,388 kWh. Since PG&E only gets a small fraction of its energy from renewable sources, we will create a smart grid that can produce enough renewable energy to power UCSC, or at least substantially increase the proportion of renewable energy being used in comparison to non-renewable energy. Additionally, any excess energy would be sold to PG&E, via net metering since we would be reviving credit for the energy. This ensures that UCSC will always be receiving energy at no additional cost. Since our solar panels will be gathering most of its energy during the day, it allows us to “store” energy with PG&E.

The UC MBEST center has 500 acres available for development and the total solar radiation that is available across this area is approximately 3,691,975,000 kWh. We calculated this figure by taking the average solar radiation per square meter per day. Average sunlight intensity in the cities of Santa Cruz and Monterey is $5.0\ \mathrm{kWh/m^2/day}$. We calculated the total annual solar radiation that hits the 500 acres at MBEST as follows,$5.0\ \mathrm{kWh/m^2/day} \times 365\mathrm{days} \times 4046.86\mathrm{m}^2 = 3{,}691{,}975{,}000\ \mathrm{kWh}$, where 500 acres = $4046.86\mathrm{m}^2$. Based on our calculations, it is clear that there is more than enough energy available.

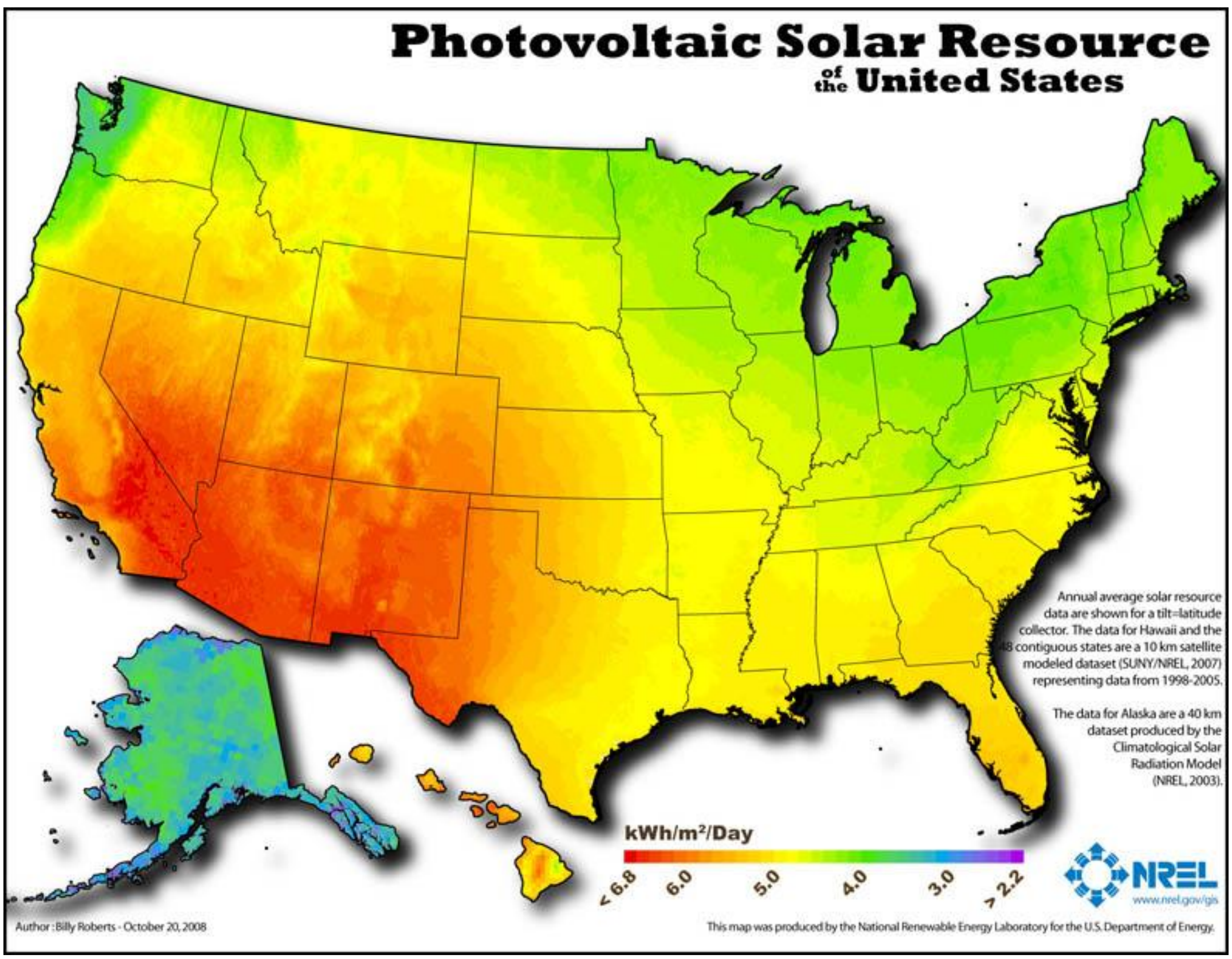

Figure 3: Average Annual Sunlight Intensity in the United States (kWh/m^2/day)

Analyses:

There are many different aspects to consider when starting this project. On the planning side, we need to know as much as possible for the efficiency, benefits, costs, and output. For the development, it is essential to get all the products, parts, and people needed and to consider the regulations and receive all permissions necessary to complete the project.

First, we need to make a blueprint or schedule of what the project looks like and how we will take action on it. Figure 4 below illustrates the layout of the UC MBEST development site (ucmbest.org).

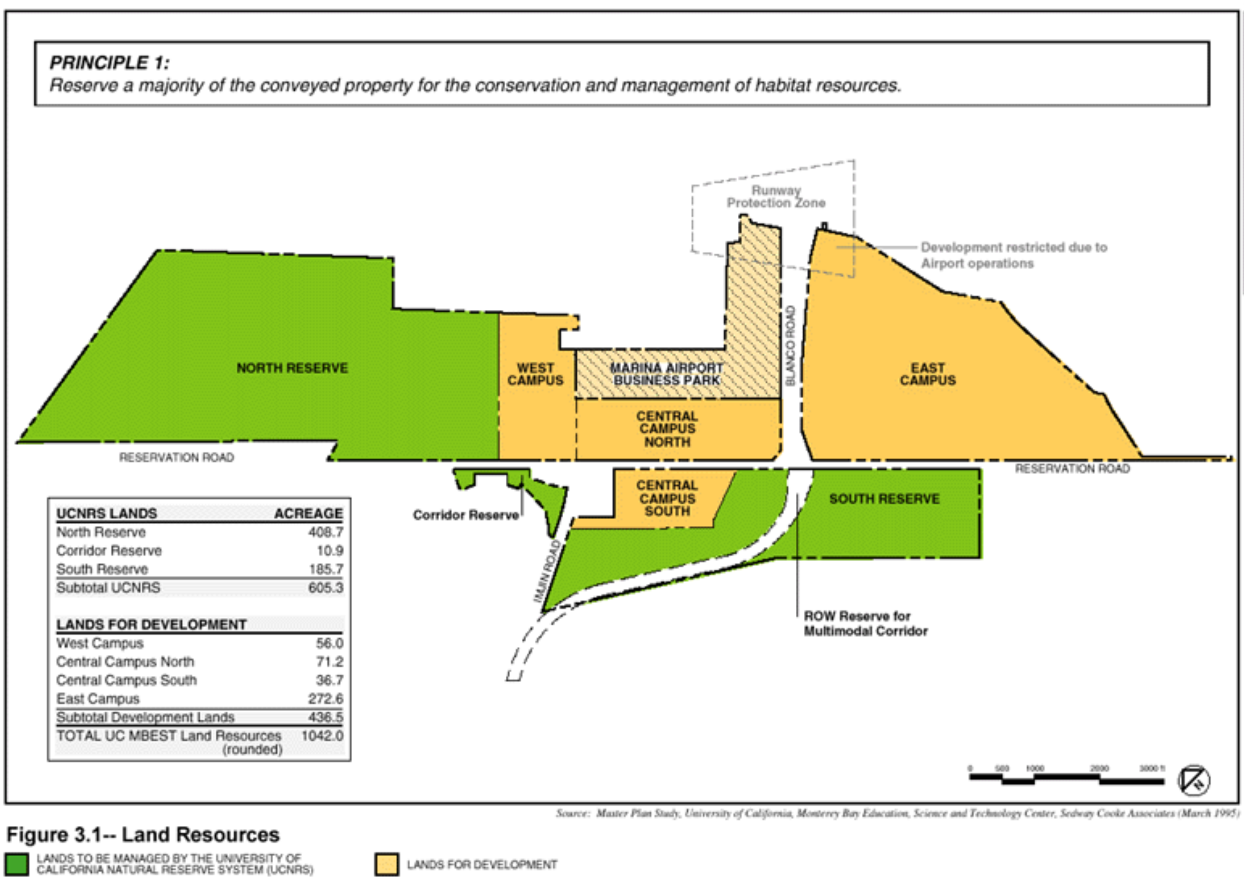

Figure 4: UCMBEST Development Site

Looking at the development site, there are two divisions, the reserves and the campus. The reserve sections are primarily saved and untouched so that the species of the natural habitat of the area are protected. This is to ensure that the land, plants, and animals in the environment don't get destructed and ruined. The campus sections are to be saved for industrial buildings, but instead, this is the area that we look to as an opportunity to create a renewable source of energy for the UCSC campus.

Over all the campus sections, there seems to be about 436.5 total acres available for development. The east campus seems to be the most suitable spot for our solar panels to be implemented. According to calculations made previously, we can see that the total kWh hitting the land per year is 3,691,975,000. If we build upon 400 acres out of the 436.5, assuming that not all of the land can be used, then we divide 3,691,975,000 kWh per year by 400 acres, yielding 9,229,937.5 kWh per year per acre. Our school needs 42,000,000 kWh per year and we can assume from all the power losses that our efficiency is at 11%. Thus, 42,000,000 divided by 0.11, we get 3.81×10^8 kWh per year. This is the amount that is needed from assuming our efficiency to be 11%. So, 3.81×10^8 kWh per year divided by 9,229,937.5 kWh per year per acre gives us 41.37 acres. 41.37 acres is the total amount of acres we need from the UC MBEST site to cover for the total energy consumption that our school requires. If only 41 acres is needed for our school, then the other 359 acres can be used to power our school approximately eight times. Technically, since that is not feasible, we can use this extra land to power other schools, homes, or even sell it back to PG&E and/or other electricity companies.

Now, with this blueprint and data, we can propose this information to UC MBEST and get approval. After we get the approval, we have a couple different options as to which solar panels we can use.

Recommended Technologies:

Solar Panels:

After closely examining various solar panels, we decided that the solar panel we think will be the most effective for our project is monocrystalline. By looking at Table 1, it is clear why we made this decision. Monocrystalline has the highest efficiency compared to its alternatives, meaning that the power output per square meter will be greater. This allows us to keep the amount of area lower, leading to a low maintenance cost . The size of our solar panels are 10 ft by 5 ft and we will need approximately 41,818 solar panels. We calculated this by calculating the power output of farm $P = 1000\left(\frac{2.76\times10^{8}\mathrm{kWh}}{24\times365}\right) = 4.7\times10^{7}\mathrm{W}$and comparing it to the output of a 560W solar panel with dimensions of 10 ft by 5 ft. By dividing our power output, we found that the number of solar panels needed was 41,818. We will be connecting these solar panels in three portions because we need to utilize a three phase system. Each portion will be connected to an inverter, 120 degrees out of phase.

	Appearance	Efficiency	Cost	Size
Mono	Dark Blue, with continues crystal lattice structure	12-16%	\$0.75/ W	Small
Poly	Speckled blue with small grains of monocrystalline silicon	10-12%	\$0.62/W	Bigger than mono
Amorph	Dark and flexible with less atom order and thin film of silicon	6-7%	\$0.69/W	Large Sizes

Table 1: Solar Panel Specs

Transmission Lines:

Providing our own transmission lines will work to our advantage. After doing extensive research, we discovered that power theft is a serious issue for smart grid owners. Providing our own transmission lines will help prevent this issue. The distance from UC MBEST to UCSC is approximately 38 miles. The cost per mile of a transmission line cost is $5 per feet for a three phase power line. A mile of transmission line will cost $80,000. Transmitting power from UC MBEST to UCSC (38 miles) will cost $2,960,000; additional costs (including engineering design, permitting, legal, and construction costs) have added another $200,000 to the cost of initial installation. This gives us a total of $3,160.000. For distribution among campus, the current power lines that are installed can be used. It is a bit unclear of how much this would cost since we would be buying these cables from PG&E.

Problems occur when transmitting power over large distances because transmissions lines must carry large voltage and low current. The reason for this is that the power loss in a transmission line is $P = I^2R$; I is the current on the line and R is the internal resistance of the line. Hence, stepping up the voltage before the transmission process is essential for proper functionality. This brings us to our next topic on transformers.

Figure 5: AC Transmission Lines

Transformers:

As mentioned in the previous section, stepping up the voltage before the transmission process optimizes our transmission efficiency. After we convert from DC to AC, we will look to step up the voltage while lowering the current of our transmission line. We need a step up transformer that does this. Transformers are specifically made to meet certain specs, so the cost of a transformer, as you would imagine, is extremely expensive. We need a step up and step down transformer.

Once our line reaches Santa Cruz, we want to step down the voltages to safe levels, which we can accomplish by using a step up transformer. A step down does the exact opposite as a step up transformer, instead of raising the voltage and lowering the current, it lowers the voltage and raises the current.

Figure 6: Power Transformer

The losses during this process are non-negligible. We must take this into account in order to properly calculate the overall efficiency of our system. Non-ideal transformers have very low power losses, as the designs are meant to do so. The total efficiency for modern transformers is 95%.

Inverters:

Before transmitting our power from UC MBEST to UCSC, we must convert our power from DC to AC because DC isn't very effective when transmitting over large distances. Most power lines carry three phase power, meaning that the voltages are offset by 120 degrees, allowing us to deliver constant power to our load.

Figure 7: Inverter Connected to Solar Panels

Embedded system:

Our team decided that our solar panels will track the sun as they move so we can increase our overall efficiency. The way we will do this is through the use of an embedded system. Our solar panels will have two degrees of freedom, one that will track in the horizontal orientation, the other in the vertical direction. We will use several components including the following:

Microcontroller:

Our microcontroller will be our main control unit. It takes data from our sensors, specifically our photoresistor and encoders, to move our solar panels to desired locations.

Photoresistor:

A photoresistor tells us the sun intensity. The way that we will be using this sensor is by placing it on a solar panel. We will then move our solar panels in the vertical direction and once we finish finding the maximum sun intensity, we will set our vertical orientation stationary. We will then scan in the horizontal direction until maximum intensity is found. This process will occur at a certain frequency, by checking frequently, we will optimize our efficiency.

Encoders:

Our system will have optical encoders that will trigger a high and low signal as the motors are moving. By counting the number of high and low signals, we will know where our solar panel is currently facing. When our photo resistor outputs the highest value, that is where we will orient our solar panel for both the vertical and horizontal positions.

Motors:

Two motors will be integrated into this design; one motor will move our solar panel in the vertical position while the other will move our panels into the horizontal position. These motors will serve as an output and our encoders and servos will serve as inputs.

Master and Slave System:

In order to save time and money, our solar farm will have a master solar panel that will scan every 15 minutes. When it finishes scanning, it will tell the other solar panels to orient themselves in the same direction. The master solar panel will do this by telling the motors to move until it reaches a certain encoder count for each motor, which will align all of the solar panels in the same direction.

Meter:

Once our transmission lines reach Santa Cruz, we will connect our grid to PG&E's grid in order to monitor the energy flow from our grid to and from the larger grid. A smart meter will keep track of all of the power flow. A meter allows us to receive credit for the excess energy.

Strategies/Example Solar Farm:

Since our project is still in its early phase, we can look up to another solar farm as a father figure guide. One solar farm project that is currently in progress is called the Topaz Solar Farm. This is a great example that we could potentially base our project off of because it is among the world's biggest solar farms. It is a 550MW power plant being built in the San Luis Obispo County. The construction began in November 2011 and is projected to be completed in 2015. It is expected to be approximately a $2 billion project that will create about 400 construction jobs and generate about 1,096 GWh. If we set aside all of our calculations and decide to go with the same exact plan that the Topaz Solar Farm is going with but scaled down to our size and needs, then we can compare the size of the solar farms. The Topaz Solar Farm is built on 9.5 square miles, or 25 square kilometers. This equates to approximately 6080 acres, whereas the UCMBEST site is only about 450 acres.

The Topaz Solar Farm is approximately 13.5 times larger than what we wish to accomplish at UC MBEST. Assuming that not everything will be precisely linear with the Topaz Solar Farm, we can scale it down by approximately 13 times. If we use the same specs as the Topaz Solar Farm and scale it down by this ratio, UC MBEST should be a 42 MW solar power plant and generate approximately 84GWh per year, assuming it is linear. According to the First Solar site, which is the solar company overseeing this project, it will power 160,000 average homes and remove 377,000 tons of CO_2 annually. If we make the same linear assumptions, then the UCMBEST will power 12,300 homes and remove 29,000 tons of CO_2.

Timeline/Costs:

Our timeline can only be made using realistic assumptions and not physical hard evidence, so we can only plan our schedule and approximate how long it will take. We believe that if we are heavily dedicated and focus completely on this project, we can get this project completed in less than 4 years. We assume that it will take one dedicated year of planning, 1-2 years of receiving permits and funding, and another year of construction. This may seem like a long time, but we have done nothing with the UC MBEST land for about 20 years. During this time, all the land and money we have been using for this has been almost entirely wasted; we could have started and even completed this project many years ago. Now, of course, that our technology of renewable energy has advanced, it would be much easier and much more efficient that if we would have built it before. Also, if we keep the site maintained, it could last up to 20 years or more. During this time, we would be slowly making back the money that we have lost, while potentially replacing the energy that we are consuming with renewable energy. Not only that, but with the extra electricity generated, we can sell this back to PG&E and even provide extra energy to other sources that are in need. Additionally, any investors that might be interested in this site will be more keen to investing in this project due to the fact that there is already development on it that produces a huge profit. UC MBEST can be considered an enormous asset as opposed to a liability.

<u>Our approximate cost:</u>

Solar panels $21,000,000

Transformers $12,000,000

Transmission Lines $3,000,000

Construction Cost $25,000,000

Total: $61,000,000

Regulation:

Before implementing such a renewable energy system, the installer would need to obtain various permits and agreements with the Monterey County Resources Management/Building Services Agency and PG&E.

In October 2009, Governor Arnold Shwarzenegger signed into law AB 920, which requires California utilities to compensate net energy metering to customers. This process serves as a storage utility for excess energy generation. Since at certain times we will be generating more electricity than we consume, it would work to our advantage to gain future energy credit from PG&E.

SB 594, a law that went into effect in PG&E utility territory February 2014, now allows property owners to aggregate the electricity load of multiple utility meters scattered throughout a single parcel or multiple continuous parcels and credit the bills with a single "net metered" installation. This will ultimately save us time and money.

Work Contributions:

Ricardo Salcedo: Calculations, Recommended Technology, Abstract.

Dylan Moon: Output/Analysis, Calculations, Strategies, Timeline/Costs.

John Shokohi: History/Overview

Aristotle Daphnis: Introduction, Inputs, Editing/Proofreading.

References

Sean, Dan S. “Which Solar Panel Type is the Best? Mono-, Polycrystalline or Thin Film?” June 2014. Web. 04 June 2014.

Smith, Rose. “Topaz Solar Farm.” *Verically Intergrated Utility-Scale PV Power Solutions* Provider. N.P., 08 May 2013. Web. 03 June 2014.

Swedon, John. “*Eather For Monterey, California*, USA. “N.P., 06 May 2012. Web.4 June 2014. <eather For Monterey, California, USA>.

Gardner, Phil. "Topaz Solar Farm." *Vertically Integrated Utility-Scale PV Power Solutions Provider*. N.p., 06 May 2013. Web. 13 June 2014.

Coleman, Micheal. "MBEST Development." *MBEST Development*. N.p., 12 July 2010. Web. 13 June 2014.

"Tiered Base Plan." *Tiered Base Plan*. N.p., 10 Apr. 2014. Web. 13 June 2014.

"UCSC Physical Plant - Energy Services - Utility Providers." *UCSC Physical Plant - Energy Services - Utility Providers*. N.p., 8 Apr. 2008. Web. 13 June 2014.

Sedwa, Ahmed. "Unit Substation Transformer." *Unit Substation Transformer*. N.p., 3 Dec. 2011. Web. 13 June 2014.

Lock, Erik. "Underground vs. Overhead: Power Line Installation-Cost Comparison and Mitigation." - *Electric Light & Power*. N.p., 28 Sept. 2010. Web. 13 June 2014.

Barnes, Malcolm. *Practical Variable Speed Drives and Power Electronics*. N.p, n.d. Oxford. Web.

Bedford, Hoft. *Principles of Inverter Circuits*. Ney York: John Wiley & Sons, 2010. Web.

"Solar Maps." *NREL: Dynamic Maps, GIS Data, and Analysis Tools* -. N.p., 27 Nov. 1999. Web. 12 June 2014.