

Sun Spotters Solar Charging Station

Fall 2014 Environmental Science Capstone Project



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In conjunction with the Campus Center for Appropriate Technology

http://www.appropedia.org/CCAT_Solar_Charging_Station

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Solar, charging, station, cellphone, laptop, tablet, renewable, energy, Humboldt State University, demonstration, Campus Center of Appropriate Technology, off-grid, stand alone, CCAT, battery

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1. Description:

The goal of this report is to demonstrate the context and process by which a solar charging station was constructed at Humboldt State's Campus Center for Appropriate Technology (CCAT). This document should serve as a reference for future monitoring and evaluation as well as a process document for potential design replication throughout the campus.

2. Objectives:

Appropriately determine a way in which to use CCAT's donated solar panels in order to:

1. Reduced burden of energy needs at HSU with renewable alternatives through a solar charging station.
2. Provide an accessible sustainable energy source to students, faculty, and staff members.
3. Provide education to students, faculty and staff members about renewable energy and campus utility usage.
4. Create a precedent/prototype for appropriate on-campus utility usage.
5. Provide a DIY resource for those who wish to build their own charging station at http://www.appropedia.org/CCAT_Solar_Charging_Station
6. Analyze cost, buyback, and energy return on investment.

3. Background:

In the summer of 2014, Ron and Melanie Johnson, former faculty members at HSU, donated eleven 100 W PV panels and a 4000W inverter plus charge controller. For the ENVS Capstone, we decided to take this donated system and create some type of solar cell phone/laptop charging station with it. Initially, we looked at powering heat pumps at the Wildlife Care Center in Bayside, Humboldt County, CA with this system. We found however that the pumps would require too much energy, needing about 30 panels. As a result, we were able to acquire some solar powered lights from the Schatz Energy Research Center and plan to install them at the Wildlife Care Center in order to help them achieve some of their need.

In search of a new purpose for the panels, we audited the Campus Center for Appropriate Technology and found a need for a power source which can be used to power cell phones and laptops that would be available to the wider public. We searched for the most appropriate place on the CCAT grounds and analyzed a few alternatives:

1. On top of the Green Shed
2. On top of the roof next to the Green Shed and Green Roof
3. On top of the Kiosk located in the front entryway
4. Creating a new structure that would hold the panels themselves

We eliminated option 1 from analysis due to the location being further away from the public view which would interfere with the educational opportunities which are a part of our objectives. Additionally, this spot receives only 1.47 full sun hours/day which is less than the full sun hours/day on the kiosk. Option 2 was eliminated due to the long term necessity of having to redo this structure as well as the necessary plans and permitting that would need to be acquired through Facilities Management. Though this area was somewhat preferred due to the capacity to turn it into a “hang out space” while waiting for devices to charge and the presence of the “Charge It” sign which is situated above the cob over. Ultimately, however, the long term needs for permitting and building of Option 2 rendered it unrealistic. Alternative 4 was additionally eliminated due to the same limitations as Option 2. We agreed to move forward with Alternative 3 due to the high visibility, ease of access, and the existing nature of the structure which can be used without having to submit extensive plans to Facilities Management. Additionally, the structure will only require minor retrofitting in order to be able to support the panels and this option had the most full sun hours in addition to the other benefits.

4. Constraints:

Constraints of this project include: eleven 13-year old 100 W PV panels, an extremely large 4000W inverter, and \$400 to acquire the best materials including a new battery, a more appropriately

sized inverter, and charge controller. Additionally, the spot chosen at CCAT has an average of only 2.05 full sun hours throughout the year, making it a less than efficient spot with only about half of the average full sun hours which exist in Arcata. Finally, this project must be mostly completable within the Fall 2014 semester with only minimal installation remaining for the following semester. Any later installation will be charged to Annette (CCAT Co-Director) and Annika (CCAT Project Leader) with support from the other three teammates; Rachel, John, and Kevin. This leaves the following options:

1. Utilizing the panels on the kiosk and accepting minimal efficiency
2. Raising the panels higher up on the kiosk
3. Finding a new spot which requires more time than we have due to permitting and Facilities Management approval.

5. Purpose and Need:

The purpose of this project is to provide a renewable energy source to the HSU campus community that utilizes as many existing resources as possible while also supporting the wider Humboldt Community. Additionally, students on campus tend to need a place to charge electronics and appliances. This station will allow HSU community members to simultaneously support their own morals and the environment while powering devices necessary to their education.

HSU has long held the reputation of being a sustainable “Green Campus” while doing little in terms of creating more appropriate energy sources on campus.

This project will not only provide the campus with this energy source, but will set a precedent for how to design and implement this type of energy source on the HSU campus in the future. It will also be a demonstration for those who wish to build their own. Additionally, there are many student groups on campus that need opportunities to plan, create, and build their own Appropriate Technologies in order to better understand how these systems function and how to support their community in the process. This solar charging station encourages opportunities for students and collaboration between various campus entities.

Examples of collaboration are as follows:

1. The Schatz Energy Research Center was kind enough to donate solar lights to the Wildlife Care Center.
2. The Renewable Energy Student Union partnered with us to test the IV curve of the panels so that we can make more accurate calculations and better plan the capacity of the system
3. The Engineering 215 class is building a similar charging station at the Montessori Charter School, allowing opportunities for collaboration between our group and theirs in order to compare notes/build the most effective and efficient systems.

In addition, this solar charging station can be utilized as a backup energy source when grid power fails. The battery component allows for the storage of excess solar energy that can be accessed in a time of emergency. Having this station as a reliable and consistent source of backup energy can provide more benefit than is quantifiable, as it enhances the emergency preparedness of CCAT facilities.

7. Calculations:

Our system is a two panel, 200 Watt, 12 Volt solar charging station. The proposed site for the system receives about 2.05 full sun hours per day and we are assuming a system efficiency of 80%. That means that our system has a daily energy capacity of 0.328 kWh. Multiply that by 365 days in a year and our system is capable of producing 119.72 kWh per year.

The charging station is specifically designed to charge cell phones, laptops, and tablets/ipads. The average cell phone pulls around 4 Watts of power when charging, meaning we could charge 82 cell phones per day if they were only charged an hour each and were to almost drain the battery. Alternatively, we could fully charge around 65 tablets at 5 Watts each. The system can run anything that is rated at 12 Volts and can run off a USB plug.

7.1. The Battery

Our main concern of building an off-grid system is the battery. Lead acid batteries are largely environmentally unfriendly to make (lead is a toxic chemical), have a limited life-cycle, charge slowly, and require maintenance (Buchmann, 2014). Out of our concern, we consulted with multiple solar professionals on what we should do about the battery issue.

After showing our design to Lonny Grafman, an engineering professor at Humboldt State University, he suggested we skip the battery and build a system that can only be used while the sun is shining. While our definition of an “accessible” energy source was one that could be accessed during daylight or not. Initially, we chose to move forward with this design due to the environmental implications of using a battery. The fact that *not* using the battery would reduce the ecological footprint of our project was attractive. There is literature that suggests a system could be overall more energy efficient by foregoing the battery. There is a high embedded energy cost that comes with manufacturing of a battery.

After consulting with Dan and Mark at Sun Frost Solar in Arcata both in person and via phone/email about our design, we were presented with a different opinion. Neglecting to use a battery would waste the energy that was being collected while the sun was shining and no one was out charging their device. There is potential for a system to offset more carbon dioxide emissions than were created during the manufacture of the battery.

From the information we gathered on the subject, the opinion on the battery depended on the viewpoint. If you are viewing the system from a “cradle to grave” mindset, the battery is not as efficient to a system due to the large energy/greenhouse gas input that went into making the battery. This includes emissions tied to extracting the minerals, transporting them, manufacturing each component, transportation of each component, manufacturing the battery, and transporting it to the shelf to be sold. But considering that 96% of a lead-acid battery can be recycled, according to the EPA, we viewed the benefits of off-grid energy production and emergency preparedness as outweighing these costs.

Our calculations also demonstrate that over the lifetime of this solar charging station the battery's carbon footprint will be offset by its ability to store and provide energy at times when the sun is not present, further reducing consumption from the non-renewably sourced grid.

There are many factors to consider when determining the specifications for a battery that is not only appropriate for our design, but that is as holistically sustainable as possible. The lifetime of the battery is critical when evaluating its overall sustainability. Deep-cycle batteries are more sustainable because they have a longer lifetime than alternatives, meaning they do not need to be replaced as soon. Another strategy for increasing the longevity of the system is to reduce maintenance by using a sealed battery. The more maintenance required the more chances there are for the battery to degrade. Another component of our design is the application of a charge controller that will prevent the battery from draining to below 30% (Buchmann, 2014).

The specifications of our battery as follows: 12 Volt, 35 Amp-hour lead acid deep cycle battery. Multiplying 12 V by 35 Ah we find that the battery can store 420 Watt hours. Our system should generate 328 Wh per day. To determine lifetime, the amount of cycles the battery can go through before losing their ability to hold a charge any longer must be determined. Deep-cycle batteries, when not discharged more than 30%, can get up to 1,000 cycles or more (Buchmann, 2014).

When the battery is discharged by 30%, the battery storage should be at 294 Wh ($420 \text{ Wh} * (1 - 0.3) = 294 \text{ Wh}$). To find out how long it will take to recharge, we divided 294 Wh by 328 Wh/day, which comes to 0.89 days. Lead acid batteries can take from 5 to 20 hours to discharge (Buchmann, 2014). Assuming our battery takes 15 hours to discharge down by 30%, that is 0.63 days. If a battery cycle for our system is going from 420 Wh to 294 Wh and it takes 0.89 days to charge and 0.63 days to discharge, that means a full cycle is 1.52 days. If our system can go through 1,000 cycles, then our battery should last for 4.2 years ($1,000 \text{ cycles} * 1.52 \text{ days/cycle} = 1,520 \text{ days} / 365 \text{ days per year} = 4.2 \text{ years}$). This is assuming, however, that our battery is being recharged and discharged continuously, which is not likely to happen. Keeping the battery charged means it will have a longer battery life.

With a modest calculation of the life expectancy to be 4-5 years, we concluded that the station would have greater potential to offset carbon dioxide emissions and function as a demonstration site with a battery component. Users will be able to charge their devices even when there is no sun, which is consistent with Humboldt County weather patterns, demonstrating that capturing solar energy is a reliable and viable option for new energy infrastructure. The benefits of having a consistently working station will continue user reliance on the station and will encourage them to learn the dynamics of off-grid solar.

Furthermore, a study at Stanford found that using batteries for large scale grid solar was efficient energy-wise due to the high cost and energy intensive nature of solar farms (Schwartz, 2013). Their findings suggest that the most efficient use of excess energy would be to use it to pump water upstream, allowing it to run downhill and turn a turbine (Schwartz, 2013). Since there is no infrastructure at CCAT for a pump system, the most practical use for excess energy collected would be to store it in a battery.

7.2 Buyback

7.2.1 Cost buyback:

The system will save the campus around \$20 each year in electricity costs and will therefore buy itself back in about 21 years. ($\$400/\$19.12/\text{year} = 20.88 \text{ years}$).

7.2.2 Panel energy buyback:

The panels would theoretically buy themselves back energywise in 9.19 years considering our system would generate 119.72 kWh per year and embedded energy for both panels is assumed to be 1100 kWh. However, since these panels were used previously for about 13 years in a much larger system, their cost has already been offset.

7.2.3 Carbon buyback:

Carbon buyback has been another consideration of this project and is detailed in our teams' excel workbook (available at http://www.appropedia.org/CCAT_Solar_Charging_Station). Assuming

students/faculty were charging their devices on campus (using Shell energy) if they were not using the solar charging station, assuming our charging station uses as much Carbon Dioxide equivalent a year as Shell's large scale solar, and assuming our battery lasts 5 years, we found the following results: **Our project may save 126.86 kilograms of CO2 equivalent over its lifetime.** This number, despite being very "back of the envelope", shows us with reasonable confidence that our project will save emissions. This is because the number for CO2 emissions from large scale solar (5,507 gCO₂e/yr) should be much higher than the true emissions from our small battery, already "bought back" solar panels, short lengths of wiring, 200W charge controller, and other components. If our system can save emissions with an assumed high number, it should save emissions with the true values.

8. Implementation Plan:

8.1 Materials:

For materials and cost list, see Appendix V.

8.2 Design:

_____The system will be made up of two 100-Watt panels, wired parallel at 12 Volts. The panels will be mounted vertically upon the CCAT cob demonstration wall in the front, or kiosk, by the greenhouse. The mounting material will be made up of recycled metal found on the CCAT grounds. Hardware needed should include screws, bolts, and corner braces. The kiosk roof will be checked for stability before mounting the panels, after which one will be mounted at a 30 degree angles facing south for maximum sunlight throughout the year and the other will be positioned at a more flat angle to catch maximum summer sun.

The panels will be positioned about 5 feet off the ground and will be wired parallel to MC 4 10-gauge branch connectors. (The positive wire from the panels will be equipped with a 10 - 15 Amp fuse for system safety). From there the connection continues to the charge controller, which will be enclosed in a display case against the west side of the wall. The display case will be made from metal or plastic

to prevent fire hazard. The charge controller will have a low voltage disconnect, to prevent our battery from ever becoming too drained and therefore maintain battery life. From the charge controller, the wiring (8-gauge) will run to the sealed battery through a conduit. The battery will be sealed so that no maintenance will be necessary, to further ensure the system has a long life ahead at CCAT. Minimal maintenance is also important due to the high turnover at CCAT and will ensure longer battery life. Our battery will be locked inside a battery box with ventilation, placed below the charge controller on the ground. The box will be locked to prevent theft as well as injury and will have a 10 - 15 Amp fuse close to the battery on the positive wire for safety as well.

Also, from the charge controller, there will be wiring to our load: a set of two Waytek USB plugs. These plugs run at about 10 Watts, keeping the power demand of our system low enough so that the system can keep up. One of the USB plugs will be equipped with a split chord that offers a variety of plugs that can be used for different tablets, cell phones, and laptops. This will give students the option to plug their device right in without having brought their own charger for one of the USBs. The Waytek USB plugs will run out the side of the charge controller display case for functionality and will give the charge station a sleek design.

As a safety feature the panels should be sanded and wired together with a #8 bare copper wire. Then, the same copper wiring will be used to connect the panels to a 8 foot ground rod with an acorn nut attachment. The ground rod should be buried almost the full 8 feet, ensuring that the system is grounded in case of lightning strike.

A future option for the system design is to purchase a pure sine wave inverter to hook up to the battery or charge controller. A pure sine wave inverter is a higher quality inverter that will protect any device that is plugged in. An inverter such as this would allow the station to be used on CCAT Volunteer Fridays for drill charging, running lights, or running small appliances like a radio. The inverter could be kept inside and only hooked up by employees on Volunteer Friday. The inverter should not be a permanent system component, because then it gives students the option to plug anything in. Plugging in something that pulls too many Watts will use up too much of the battery's stored energy, so

that it may low voltage disconnect and other students cannot charge their devices later. However, the inverter could be a useful feature for Volunteer Friday and should be considered for the future.

Lastly, our design will include a guest book for students to log each time they use the station and an educational sign, explaining how the system works. The sign will demonstrate to guests the different components of our system as an educational resource and as a model for replication.

8.3 Construction:

Before any construction occurred our design was presented during a CCAT Steering Committee meeting for feedback, project approval, and allocation of funding. We were awarded \$400 to go towards purchasing components needed for the system. CCAT also generously allowed us access to their tool shed and work area.

Construction will be broken up into two phases, physical and electrical. Physical construction will include mounting and creating enclosures. Electrical construction will involve wiring the system together.

8.3.1 Physical:

First, the kiosk roof should be stabilized to ensure the panels will not fall off and break during a high wind event or the like. The kiosk roof is slightly wobbly due to having a single, central support beam wedged into place. This can be stabilized by screwing it into place and adding additional support beams if necessary.

Next, the panels should be mounted. We will use hardwood, screws, and corner braces found on the CCAT grounds for this part. The kiosk roof is triangular with the panels having to sit on the apex, which will make mounting a challenge. We plan to do this by creating four metal legs on each corner of the panel, the back legs being longer to create a 30 degree angle, and then connecting the legs across the roof. There will be a cross beam connecting the legs in order to increase stability of the structure. The bottom beams may be screwed directly into the kiosk roof.

The enclosure for the charge controller shall be made of recycled material around CCAT with a window to read the display.

8.3.2 Electrical:

Electrical system work involves wiring the panels to the charge controller and battery with proper safety fuses. The electrical work also includes the wiring to the ground rod from the panels. The wiring is something that can be completed by our team, but the ground rod will have to be placed 8 feet under by Plant Ops through a work request. Electrical work will also include wiring through the proper conduits. The last stage of electrical construction will be system testing and retrofitting.

9. Monitoring and Evaluation Plan:

The success of the solar station will be gauged based on its effectiveness in developing renewable energy infrastructure and use on campus. An assessment of energy saved from the grid-tied Shell power mix will be converted to amount of carbon dioxide emissions reduced in order to quantify the solar station's effectiveness in lessening the environmental impact of our on campus energy consumption. Employees at CCAT will be given the responsibility to evaluate the effectiveness of the charging station, both its real-time use and in its capacity to provide a model for replication. We will set the station up with a guest book to aid in the monitoring and evaluation of the system.

The guest book is a Write in the Rain notebook that is permanently affixed to the kiosk alongside interpretative materials. The purpose of this book is to allow users to provide feedback to CCAT employees about maintenance concerns, instructional value, and frequency of use.

With data and feedback from the guest book, the success of the station in promoting solar adoption and knowledge alongside actual energy savings and carbon dioxide emission reductions will be evaluated.

The components used in the creation of this station will require little to no maintenance. The battery is of biggest concern, as it has a lifespan of 4-5 years in this application. In order to maximize

battery life, it needs to be recharged shortly after being discharged. If the battery is disconnected and stored for any period of time it is important that this is done so in a fully charged state.

The charge controller will ensure that the battery isn't overcharged from the solar panels and also provides a voltage disconnect to prevent over discharging. The addition of the charge controller will prevent the battery from being overcharged or drained, thereby increasing its lifespan and efficiency. Because this battery is sealed, there is no need for equalizing. Terminals may become corroded in the future and may need to be cleaned. This can be done alongside the maintenance of the other batteries located on CCAT grounds. We anticipate that the person in charge of managing the solar system on the Yurt and/or the MEOW can be delegated to monitor this system congruently, and our interpretive sign will include how to do so.

The learning outcomes, monetary savings, and carbon dioxide emission reductions will be evaluated in an on-site guestbook. The delegation of monitoring duties will be passed on to the person in charge of the other solar projects located on site. Furthermore, the site will be consistently monitored by users and students who will have access to hands on interaction with the station. The charging station is not only a practical solution to energy demand concerns on campus, but is a demonstration site. By incorporating education and demonstration into the design, there is the potential for future students and student groups/classes to perform maintenance duties and monitor the system, so that they may gain hands on experience while ensuring that all components are functioning as efficiently as possible.

10. Lessons Learned (successes and failures):

From the start of the project we faced the challenge of finding a use for the donated solar panels, since we did not want to create an energy demand nor did we want to build infrastructure that would not be utilized at full capacity. We brainstormed appropriate applications for the panels and developed a list

of high profile sites. Through the scoping process for these sites we faced various challenges and barriers that can be shared for the improvement of future community solar projects in Humboldt County. The initial challenge we faced was acquiring the necessary permitting and PG&E approval for an on-grid system on a local non-profit that has a need for renewable energy infrastructure- The Humboldt Wildlife Care Center. In order to go through this process we would have to had to extended our timeline and found further financial support without the assurance of being approved for construction. After several site visits and planning, we deemed that this site would not be feasible for our system due to bureaucratic barriers. We went through a similar process at the Mattole Charter School and the Bike Learning Center- both on HSU campus.

Once confronted with these barriers, we outreached to local professionals in the solar industry to determine further steps. We wanted to ensure that we could follow-through with a project that was not only feasible, but sustainable. There were a plethora of people who helped us along the way and our collaboration with on and off campus professionals was one of our best choices of action. Our decision to seek help when we were uncertain led us to a refined design that was very different than what we had initially drafted.

Although our project evolved from planning to use all the panels on an on-grid setting in the community to using two of the panels on a solar charging station at CCAT, we have found that our chosen application is valuable. This demonstration station shows the community what solar infrastructure can realistically be achieved in a short amount of time with limited resources and student-level knowledge on solar. Overall, the many sites we scoped refined our methods and design, leading us to create a solar charging station that provides a renewably sourced energy at no-cost to students or the University.

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Campus Center for Appropriate Technology, Humboldt State University, Arcata

Lonny Grafman, Engineering Professor, Humboldt State University, Arcata

Dr. Richard Hansis, Humboldt State University, Arcata

Monte Merrick at the Humboldt Wildlife Care Center, Bayside

Dan Moyer at Appropriate Solar, Sun Frost Refrigeration, Arcata

Bryan Norkunas at PV Cables, Redway

Kristin Radesky at Schatz Energy Resource Center, Humboldt State University, Arcata

Renewable Energy Student Union (RESU), Humboldt State University, Arcata

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Appendices:

Appendix I: Terms of Reference

Here is our initial Project Implementation Plan that we used as a group organizational tool. Our methods changed alongside our project and this document was more of an initial planning tool than an accurate representation of our process. It is shown here to give an example of various tasks and deadlines we worked with, but is not a comprehensive schedule of events.

TASKS & AVAILABLE RESOURCES/CONTACTS	DUE DATE	TASK LEAD/ NAME	SUCCESS INDICATORS/ METRICS	Hours Worked
1. Consult with professionals Resources: Dan at Appropriate Solar, Lonny Grafman, Ben Scurfield, Solar Roger	10/28/14		Received report on panels, work more than 50%	4.5
2. Test solar panels (IV Curve) and solar analysis of site Resources: RESU	11/2/14	RESU and Sun Spotters	Knowledge on what materials to buy	2.5
3. Create presentation for CCAT Steering Committee and receive feedback on project				
4. Complete Implementation Plan Resources:	10/30/14	The Sun Spotters		1.5
5. Complete Monitoring and Evaluation Plan Resources:	11/14/14	The Sun Spotters		1.5
6. Design proposal and present to CCAT Steering Committee Resources:	11/3/14	The Sun Spotters	Approval of project	3.5
7. Draft report Resources:	11/13/14	The Sun Spotters	Introduction/Background/Project Description/Problem Statement & Justification Methods & Materials Implementation Plan	

			Evaluation, Monitoring, Maintenance Appendix	
8. Final Report Resources:	12/3/14	The Sun Spotters		
9. Buy Materials/ Request Donations Resources: NAPA, Facilities Mgmt., Sun Valley	11/22/14	The Sun Spotters		
10. Construct charging station at CCAT Resources:	11/24/14- 12/3/14	The Sun Spotters		
11. Complete solar light project at Wildlife Care Center Resources: Monte at Center, Kristin at SERC	12/1/14	Annika with SS		

Appendix II: Energy Calculations

Daily Energy	164 Wh/day			Full Sun Hours	2.05 hrs/day
	0.164 kWh/day			Panel Power	100 Watts
Panel number	2			Balance of System	0.8
Total energy	0.328 kWh/day				
System voltage	12 V				Inverter Size Pic
# Cell phones	1 phone	How to use spreadsheet: Input new numbers in pink cells and the grey cells will change to reflect the new data. This spreadsheet was designed for the solar charging station at CCAT, which will be a 200W, two panel, off-grid system for cellphone/laptop charging.			
Cell phone charging power	4 Watts				
Charge time	1 hour				
Energy use	0.004 kWh				
Our system could theoretically charge:	82 cell phones/day				
# Cuisinart Smart Stick Hand Blender	1 blender			# Electric drill batteries	1 drill battery
Hand blender run power	200 Watts			Drill power	200 Watts
Use time	0.1 hrs			Charge time	1 hrs
Energy use	0.02 kWh			Energy use	0.2 kWh
Our system could theoretically run:	16.4 hand blenders/day			Our system could charge:	1.64 12 V drill batteries/day
# Laptops	1 laptop			# Xmas light strings	1 string
Laptop charge power	44 Watts			Light power	25 Watts
Charge time	2 hrs			Use time	2 hrs
Energy use	0.088 kWh			Energy use	0.05 kWh
Our system could theoretically run:	3.73 laptops/day			Our system could run these lights for about	12 hours
Note: Anything that could not be run through a USB port will require an inverter. Currently, this is not included in our design, but could be in the future.				# Tablets/ipads	1 tablet
				Tablet/ipad power	5 Watts
				Charge time	1 hrs
				Energy use	0.005 kWh
				Our system could charge:	65.6 tablets/ipads per day

Appendix III: Embedded Energy Cost Buyback

Hypothetical Solar Panel Buy Back		Our system is: 2 100W panels, with 2.05 hrs/day of full sun, 0.8 efficiency, and an estimated \$0.16/kWh			
				# of Panels	2
Daily Energy:	0.328 kwh/day			Panel Size	100 Watts
Yearly Energy:	119.72 kwh/year			Price/Watt	1.5 \$/W
Yearly Electricity Price:	19.155 \$/year			Electric Rate	0.16 \$/kWh
Yearly Electricity Price/4:	4.79 \$/yr for each component			Full Sun Hours Yearly Averag	2.05 hrs/day
Panel Cost	300 \$			Efficiency of System	0.8
Buy Back	15.66 years			Days in a Year	365
				W-KW	0.001
Solar Panel Embedded Energy				Energy Embedded in Panel	5500 kwh/kw
Embedded Energy	1100 kwh				
Pay Back	9.19 years				
Buy Back From Other System Components		Cost:	Buy back time:		
Battery	80 \$		16.71 yrs		Rachael
Charge controller (estimate)	12 \$		2.51 yrs		John
Inverter	65 \$		13.57 yrs		Annette
USB Split chords	25 \$		5.22 yrs		Kevin
			Total buyback:		
Total system cost:	400 \$		20.88 yrs		
Student/faculty Savings					
# Cell phones:	29930 cell phone		# Laptops	1000 laptop	
Cell phone power:	4 Watts		Laptop charge p	44 Watts	
Charge time:	1 hrs		Charge time	2 hrs	
Energy use:	119.72 kWh		Energy use	88 kWh	
Dollar savings:	19.1552 \$		Dollar savings:	14.08 \$	

Appendix IV: Carbon Intensity from Shell Energy

CO2 From Solar versus the Grid			Greenhouse Gas Intensity for Electricity		Shell Energy Retail Power Mix	
0.328 kWh/day			Source	Intensity (gCO2e/kWh)	Source	0%
119.72 kWh/year			Biomass	18	Biomass & Waste	0.017
			Geothermal	45	Geothermal	0.027
CO2 From Our Solar Charging Station			Solar	46	Small hydro	0
5507.12 gCO2e/year			Wind	12	Solar	0.006
			Coal	1001	Wind	0.23
CO2 From Shell Power Mix			Hydro	4	Coal	0
Source	kWh/yr	gCO2e/yr	Nat gas	469	Large hydro	0.08
Biomass	2.04	36.63	Nuclear	16	Natural gas	0.32
Geothermal	3.23	145.46	Other	365.44	Nuclear	0.04
Small Hydro	0.00	0.00	Source:		OTHER?	0.28
Solar	0.72	33.04	Silas Biggins - HSU Energy Manager		Total	1
Wind	27.54	330.43			Source:	
Coal	0.00	0.00			shell.com/us/energy	
Large Hydro	9.58	38.31				
Natural Gas	38.31	17967.58				
Nuclear	4.79	76.62				
Other	33.52	12250.13				
Total	119.72	30878.21				
CO2e Savings per Year: 25371.09 gCO2e/yr						
Project Life Years:	5 yrs					
CO2e Savings per Project Lifetime	126.86 kgCO2e					

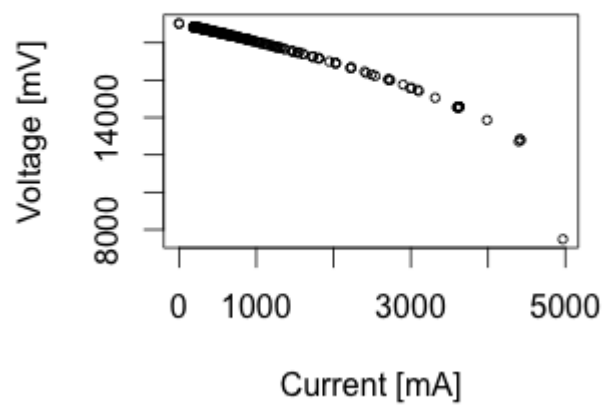
Assumptions: Students/faculty would be charging their laptops/tablets/cell phones elsewhere on campus if not at CCAT, using Shell Power. CCAT solar has the same CO2 intensity as Shell's solar power.

Appendix V: Materials

Item	Location acquired	Cost
Sealed battery	www.amazon.com	\$75
USB split chords		\$25
Charge Controller	Appropriate Dan	\$66
Hardware	CCAT	Free!!
Copper wire #8 bare, 20 feet	www.pv-cables.com (Redway, CA)	\$5
Ground rod, 8 feet	Hensel's Ace Hardware	\$17
Acorn nut	Hensel's Ace Hardware	\$5
Panel wire, 8 feet	Solar Rodger	Free!

MC 4 branch connector	www.pv-cables.com (Redway, CA)	\$8 X 2
Multi Contact MC 4 10 AWG Output PV cable 50 ft	www.pv-cables.com (Redway, CA)	\$16.50
Conduit	CCAT	Free!
Battery box with lock		
Fuse block 10 - 15 Amps near battery		
Waytek USB plug for load	Waytek Inc.	\$43
Housing for charge controller	CCAT	Free!
100W Panels (2-4)	Donated by Ron and Melanie Johnson	Free!
Building materials	CCAT	Free!

Appendix VI: IV Curve Test from the Renewable Energy Student Union



Appendix VII: Timesheets

Annette's Hours for the Sun Spotters Fall '14			
Date	Activity	Hours worked	Cumulative Hours
09/09/2014	Team meeting	1	1
09/11/2014	Team meeting/solar assessment of bike learning center	2	3
09/13/2014	Meeting with TC	1	4
09/15/2014	Team meeting	1	5
09/16/2014	Bibliography research	1	6
9/22/2014	Brainstorming	1	7
9/23/2014	Team meeting and follow up with Solar Roger	1	8
9/28/2014	Wildlife care center assessment/Photo Taking	1	9
9/30/2014	Brainstorming	1	10
10/02/2014	Brainstorming	2	12
10/05/2014	Team Meeting	3	15
10/07/2014	Brainstorming, Meeting with Kristin from Schatz, acquire Solar Lights	2	17
10/09/2014	Solar light testing	2	19
10/14/2014	Team Meeting	1	20
10/16/2014	Team Rendezvous, Lonny meet up with Annika	2	22
10/19/2014	Brainstorming	3	25
10/21/2014	Team Meeting	2	27
10/23/2014	Team Meeting/Planning	2	29
10/26/2014	Group work on Implementation Plan	3	32
10/28/2014	Consulted with Ben Scurfield briefly by phone. Worked on Report.	2	34
10/30/2014	Report Writing, Brainstorming	2	36
11/02/2014	Panel Testing with RESU, Planning for Presentation	3	39
11/03/2014	Present project to CCAT Steering Committee	1	40
11/04/2014	Brainstorming, Component Research	2	42
11/06/2014	Emailed info to Ben Scurfield, Wrote and Sent Thank You letter to Ron and Melanie Johnson	2	44
11/11/2014	Brainstorming, Component Research, Tested Charge Controller found in free pile at CCAT.	2	46

11/13/2014	Independent Report Writing	2	48
11/16/2014	Team Meeting/Acquiring Equipment	3	51
11/18/2014	Ground Rendezvous	2	53
11/20/2014	Report Writing	2	55
11/21/2014	Roof reinforcement, Construction and Design Considerations, Took Photos	3	58
11/23/2014	Team Meeting: Found Annika's note and panel after adding initial mounts, Construction Considerations, Report Writing	2	60
11/30/14	Edited Photos, Added to Appropedia Page	4	64
12/02/2014	Rack Construction, Design Considerations	2	66
12/04/2014	Group Rendezvous, Design Considerations, Interpretive Sign Considerations	2	68
12/07/2014	Mounting Considerations, Glued on Pondliner to mark mounting points	3	71
12/09/2014	Report writing, Photo Editing	3	74
12/10/2014	Report writing	3	77
12/11/2014	Plans to Implement Final Phases of Construction	3	80
12/12/2014	Construction and Appropedia Additions	4	84
12/14/2014	Construction and Interpretive Sign Design	3	87
Unknown	Future Construction	6	93
Unknown	Interpretive Sign Creation	4	97
Unknown	Appropedia Updates after Finalized	3	100
Total Hours:			100