Solar Roller - Solar Powered USB Charging Station

A Senior Project
presented to
the Faculty of the Electrical Engineering Department
California Polytechnic State University, San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Bachelor of Science

by

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Abstract

As the necessity for renewable energy increases, solar power becomes more and more prevalent. At the same time, as technology increases, the necessity for charging one's electronic devices also increases. The Solar Roller merges solar energy with the ability to charge one's electronic device in one compact cart. The Solar Roller is a solar-powered USB charging station that allows people of all backgrounds to develop a better understanding of alternative fuels, while charging their USB device. It has a touch screen display that provides voltage levels of the battery as well as a TV that displays solar powered information. The goal is to create a useful solar-powered system to charge people's devices, while providing information about the opportunities that solar power can provide.

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Chapter 1. Introduction

In recent years, the consequences of our reliance on fossil fuels has begun to make an impact on the environment, as global temperatures have continued to rise year by year. In order to combat this change, alternative sources of energy, such as wind and solar, must take over the leading role of fossil fuels. Renewable forms of energy have been gaining traction, as more and more homeowners are installing rooftop solar systems, and there have been many large-scale solar farms constructed in the past few years. These successful installations of solar and other forms of renewable energy have proven that fossil fuels may no longer need to be relied upon, and the addition of more will only be beneficial.

According to the United State Energy Information Administration, the leveled energy costs of solar energy are much higher compared to common sources such as natural gas, coal, and various renewable sources, as seen in Table 1-1. Solar energy is much more expensive than natural gas per kwH over twenty years [1]. These values take into consideration the high costs of infrastructure and maintenance; not just the raw consumable cost. Despite this, solar energy has several advantages. As non-renewable resources are depleted, their cost will increase exponentially if we do not begin using more sources of renewable energy. Other alternatives like wind power and hydroelectric power are limited by where they can be placed. Solar energy, while initially expensive, can be placed and moved virtually anywhere. If previous trends continue, the cost of solar cells will continue to fall, making solar energy economically viable.

Table 1-1: Levelized Costs of Different Power Plants

Power Plant Type	Cost $/kW-hr
Coal	$0.095-0.15
Natural Gas	$0.07-0.14
Nuclear	$0.095
Wind	$0.07-0.20
Solar PV	$0.125
Solar Thermal	$0.24
Geothermal	$0.05
Biomass	$0.10
Hydro	$0.08

The obvious benefit of solar power over fossil fuels is that they are essentially 100% clean energy, producing zero emissions that directly contribute to climate change and environmental concerns. Extracting and using fossil fuels is expensive and harmful to the environment. Greenhouse gases, which are produced when fossil fuels are burned, lead to rising global temperatures and climate change. Climate change contributes to serious environmental and public health issues, including extreme weather events, rising sea levels, and ecosystem changes. Figure 1-1 shows Renewable Energy Corporation's statistics of the carbon dioxide emissions of Coal, Natural Gas, and Solar in grams of CO2 per kWh of energy. Solar emissions has a mere fraction of the emissions of the other two.

Solar panels also provide energy reliability, security, and independence. The rising and setting of the sun is obviously extremely consistent and reliable. All around the world, information is available on when the sun rises and falls every day. On top of reliability, there is security in the fact that no one can buy the sun or turn it into a monopoly. People do not have the

power or ability to stop the sun from coming up everyday. Since the “fuel” for solar panels cannot be bought or monopolized, there is energy independence. It is free for all to use.

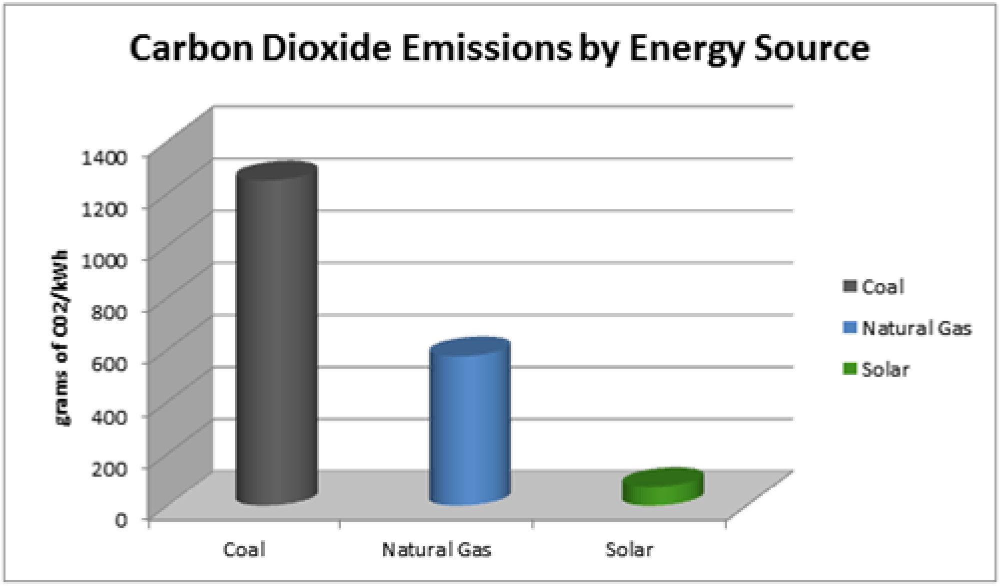

Figure 1-1. Coal, Natural Gas, and Solar Emissions

Solar power as we know it today is a fairly modern technology, being in mainstream use since the 1950’s. In 1953, a group of three scientists discovered silicon solar cells, which were only capable of producing enough electricity to run small devices. At this point, it was estimated that a 1-Watt solar cell cost around $300, much improvements had to be done to make them more affordable and usable for the average consumer. In the 1970’s, Exxon spearheaded research towards more affordable solar cells. From the 1970’s to the 1990’s, solar panels started to become more relevant, not just for big companies that could afford them. Figure 1-2 shows solar panels being installed in the 1970’s, and Figure 1-3 shows a solar panel field from the 2000’s.

The relevance of solar panels has increased exponentially in just the last 40 years. Now, in 2017, a high-quality 150W solar panel typically costs around $215. This makes it more reasonable to fund for a homeowner.

Figure 1-2. Solar Panel Installation in 1970s

Figure 1-3. Solar Panel Field in the 2000's

With all of the advantages of solar panels and their decreasing prices, the solar industry has grown exponentially in recent years. According to the Solar Energy Industries Association, the installations of solar panels in the US reached an all-time high in 2016, seen in Figure 1-4. This is mainly due to the commercial prices, which have fallen 58% since 2012 and by 16% just in the last year [2], as shown in Figure 1-5. Solar energy isn't just big in the United States, but all around the world. According to the International Energy Agency (IEA), "about half a million solar panels were installed every day around the world last year (2015)" [3]. The IEA also predicts that Solar power could be the world's main energy source by 2050 [4]. Overall, renewable energy is a growing industry, and it is continuing to gain popularity worldwide, from residential to commercial to industrial uses.

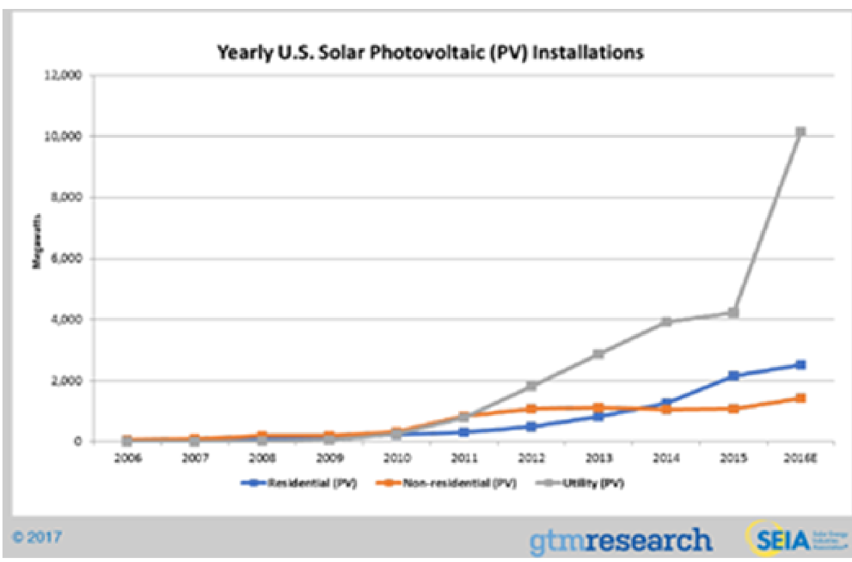

Figure 1-4. Growth in Solar Photovoltaic Installations

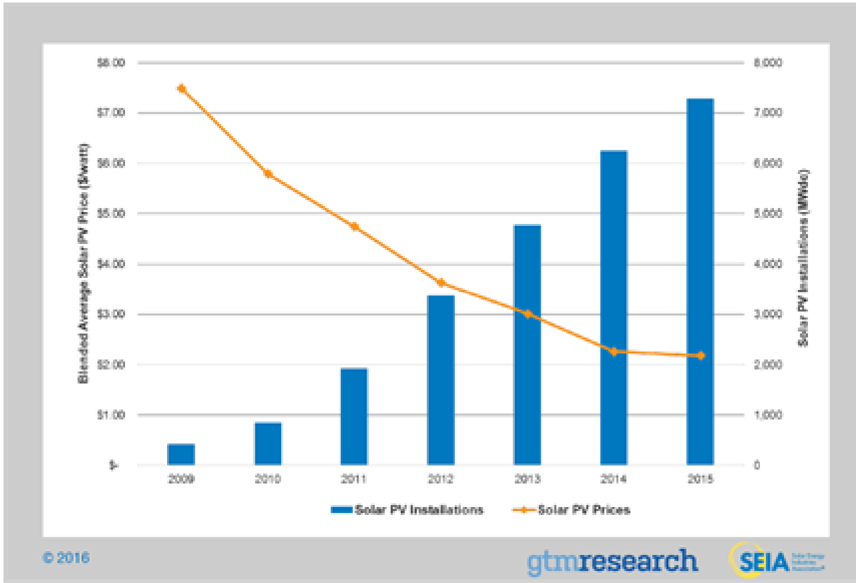

Figure 1-5. Price Decrease and Installations Increase of Solar PV

Chapter 2. Background

Renewable energy, more specifically solar, has begun to grow in popularity throughout the world. However, many people are still unaware about the benefits of solar power, and lack a strong education on the topic. The EU, a very well-developed solar market, still generates only 3% of its energy from solar. Part of this can be attributed to a lack of understanding about solar, which leads to improper use or poor maintenance of the system, as well as not installing solar altogether [1]. The goal of the Solar Roller proposed by this senior project is to educate people on the importance of alternative forms of energy such as solar power, and provide an immersive experience in which people can have hands-on involvement through DC devices including device charging and audio/video playback.

Solar energy is a topic that has gained more and more recognition in the recent years, yet many people are unaware of the benefits that it can provide. According to an article written by SolarTown, many people around the world have reservations about adopting solar energy. The most common issue with the adoption of solar energy is the perceived price. According to a survey taken from citizens in the United States, Japan, China, and India, 45% of people do not believe using solar energy is profitable [2]. While the cost of solar infrastructure is high, it is important to consider the effects on the environment that adopting solar energy would bring. Economically, many do not consider the eventual costs of dealing with environmental damages and depleting sources of non-renewable energy. Of the people surveyed, 46% thought that solar energy adoption would not provide additional jobs; a quarter feared that it would decrease employment. It is clear from these opinions that many are hesitant to begin adopting solar energy, and that better education about solar energy would be beneficial worldwide.

The most important way that the proposed Solar Roller will help educate others about solar energy is just by being seen. Laura Wisland of Clean Energy stated that in 2013, there were only 400,000 homes in the United States with rooftop solar panels [3]. Many people do not see solar energy being used, so they are not aware of it. Vehicles like the Prius and Tesla promote alternative energy use by being seen by the public consistently. By creating a product that visibly advertises its use of solar energy, we are making more people aware of solar energy and its advantages. While states like California have increased how much power is supplied through solar energy, this power is generated away from the public eye. By increasing the amount of people who are aware of the costs and benefits of solar energy, we can increase the widespread usage of renewable energies. This would persuade more companies to invest in solar energy, hopefully adding more jobs in the energy field.

While having an educational purpose, our senior project will also provide a practical charging station and media hub. According to the Pew Research Center, as of 2013, 91% of adults own a cell phone [4]. **Figure 2-1** shows the trend from Nov 2004 to May 2013 of cellphone ownership. With cell phone technology exponentially increasing since this study was taken, and the overall price of a cell phone decreasing, it is safe to assume that the number of people with a cell phone has increased to over 91% in 2017. With the large majority of people with a cell phone, there is a need for keeping them charged while on the go. There is a need for finding accessible energy in areas that normally wouldn't have an outlet. A portable charging station could help alleviate the dilemma of having an uncharged cell phone in an area without a wall outlet.

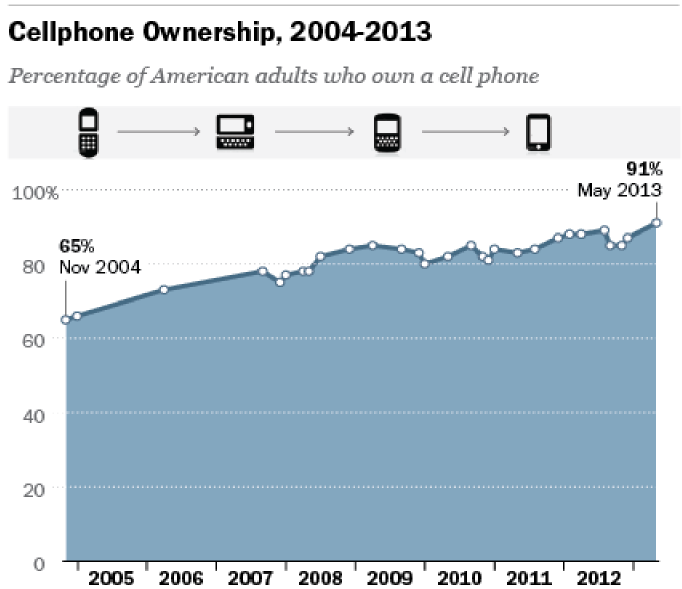

Figure 2-1. Cellphone Ownership 2004-2013

College campuses, public parks, and music festivals are some of the main target markets that would greatly benefit from a portable charging station. With around 32 million people attending music festivals each year according to a study done by Digital Music News [5], the need for charging is huge. Music festivals can range from 4-10 hours a day in an outdoor area with little to no areas to charge an electronic device. Using the statistic that 91% of adults have cell phones and 32 million people attend music festivals a year, over 29 million cell phones will be at the festivals. Most of the people using the cell phones will be using high battery usage

applications such as taking video and pictures. People need to charge their phones at music festivals, and a portable solar charging station could perfectly fix this problem.

Another area that would greatly benefit from a portable charging station is college campuses. Many college campuses have a lawn or outdoor area that students can relax, study, and eat at. At Cal Poly, Dexter Lawn is this place. Dexter Lawn is a popular area that is always filled with students that have their phones on them. Most of these students are enjoying the outdoor, so they are usually not to active on their phones. It is also safe to assume that not everyone has a fully charged phone. A portable station that the students can safely charge their phones while they enjoy the outdoors would fit in perfectly on Dexter Lawn.

There are many commercially available portable USB charging hubs, yet the majority of these are not solar-powered and are meant to be connected through a USB port on your computer or laptop. Small solar USB chargers are currently available as well, however, these have a small solar panel always connected to it and only provide charging for one or two devices at the same time. These products can also be very expensive, and not convenient for the average person to charge their device. The current products that are available are also not meant to be educational, instead they are just another item that can be bought in a store. **Figure 2-2** is an example of the commercial and personal solar-powered USB chargers that are available today in stores and online. They are very small, and do not provide external information such as the current that a connected device is being charged with, or any other educational aspect.

Figure 2-2. Commercially Available USB Solar Charger [6]

The Solar Roller is a portable solar-powered USB charging station, that includes interactive peripherals such as an LCD display for current and voltage readings, lights, and speakers, that allow for a hands-on approach to learning about solar and renewable energy. This is what makes the Solar Roller unique, is that it is intended as an educational tool to demonstrate the use of solar energy, but also is fully functional as a USB charging station. Most of the aforementioned chargers are small plug-and-play systems, while the Solar Roller is truly a learn-by-doing way to learn about solar energy. We would like to provide educational opportunities to people of all ages, and want to inform the public about where the world is headed in terms of energy, and what they can do to be a part of it.

Chapter 3. Design Requirements

Figure 3-1 shows the basic level 0 block diagram of the proposed Solar Roller, with one input coming from light (into the solar panel) and the other coming from a user, such as an auxiliary audio input. The two outputs are a 5V USB output which is used for charging a device and the port displays/audio from the user's input.

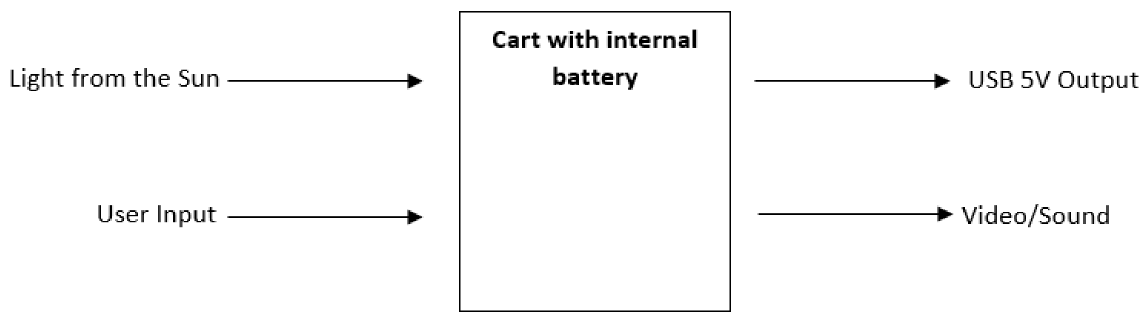

Figure 3-1. Level 0 Block Diagram

The following Table 3-1 list and details the functional decomposition for the solar roller design.

Table 3-1. Level 0 Functional Decomposition

I/O	Type	Description
Light from the Sun	Solar Panel	Takes in energy from the sun in the form of light, converts

		the light to a voltage/current
User Input	3.5mm auxiliary audio jack	Allows the user to play music through the charging station while waiting for their device to charge
USB 5V Output	USB	What the user connects their smartphone or device to charge
Video/Sound	Speaker/Display	Outputs music of the user's choice to listen to while charging their device

Figure 3-2 shows the detailed breakdown of the Solar Roller. Light is taken in as an input into the solar panel, which converts it into a voltage/current. This is then sent into the battery for storage through the charge controller, to protect overcharging of the battery. The battery is then used to power the individual USB ports, as well as the microcontroller, strand lights, DC Television, and speakers. The outputs are 5V USB ports, which will be used to charge compatible devices, as well as LCD displays under each USB port displaying the current and voltage of the port. Another output is the light from the strand lighting, which is a basic, non-interactable output. Next is the output from the DC TV, which will be a premade informational

video about solar energy or renewable energy in general, or other educational materials. The last output are speakers, which play audio of the user's choice as input through the 3.5mm auxiliary jack. Table 3-2 details the level 1 functional decomposition of the proposed solar roller.

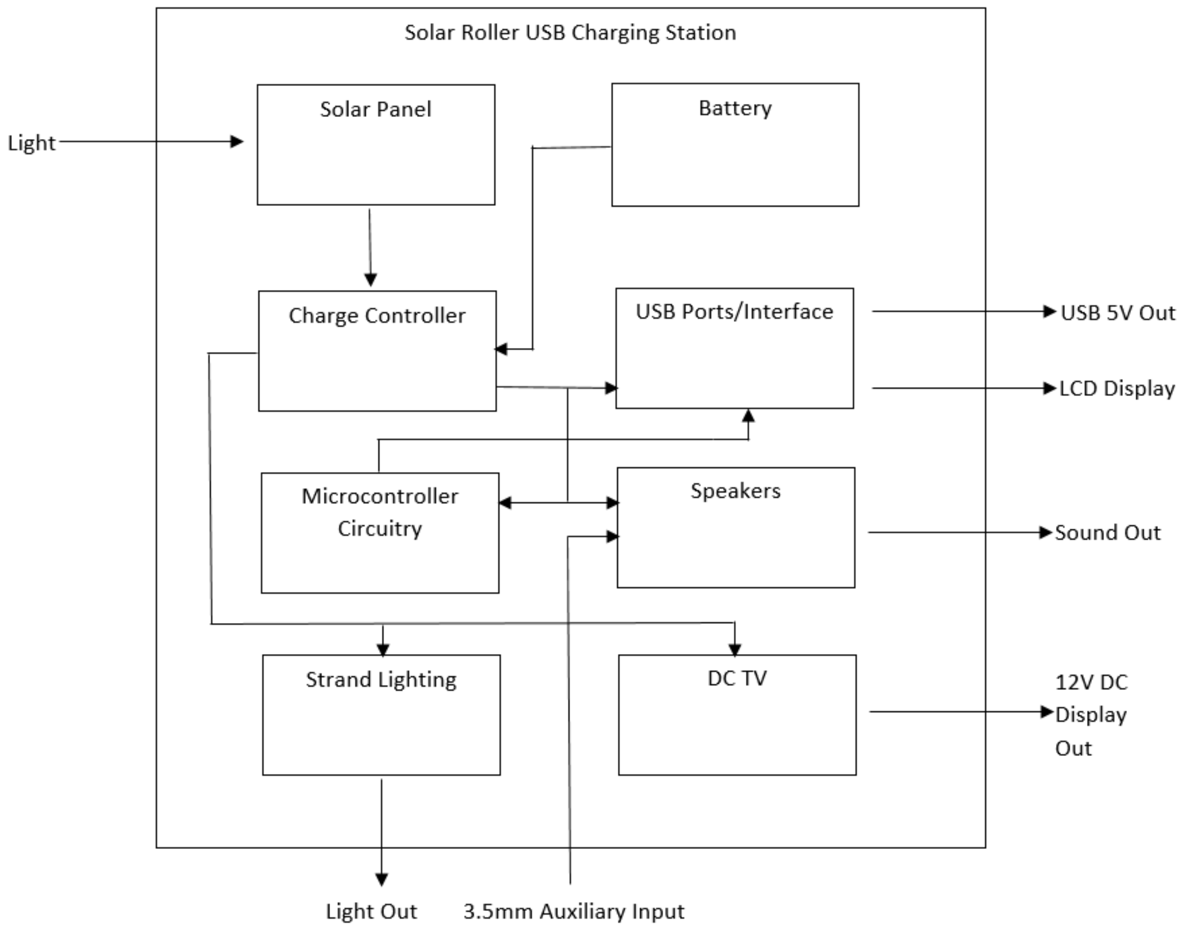

Figure 3-2. Level 1 Block Diagram

Table 3-2: Level 1 Functional Decomposition

I/O	Type	Description

Light	Solar Panel	Light is converted to current/voltage through the solar panel, is then stored in the battery which is limited by the charge controller
USB 5V Out	USB 2.0	What the user connects their smartphone or device to charge
LCD Display	Display	Small displays on each USB port that display the voltage/current of the port, controlled by a microcontroller
Sound Out	Speaker	A speaker that plays whatever is input through the 3.5mm jack by a user
Light Out	Strand Lighting	A basic output, 12V strand lighting powered by the battery

DC TV Display Out	12V DC Television	Will display a premade informational video, about solar or renewable energy

Technical Specifications

The following explains in more details specific requirements on several components in the proposed solar roller.

Load types and specifications:

- **10 USB charging ports -** Maximum of 5V, 1A each. Necessary to provide charge to up to 10 connected devices.
- **MP3 Player, Speakers, Television, String Lights -** Be able to run off a maximum of 25W. Provides entertainment to users of the Solar Roller.
- **Charge controller** - Able to deliver enough current to each branch of the circuit while also providing overcharge protection for the battery.
- **Arduino w/ LCD -** Displays current charge level of the battery and the power going to each branch of the circuit. Powered with MP3 player, speakers, and television.
- **Mobility -** Light and balanced enough for one or two people to easily maneuver.

The Solar Roller will utilize a car that is approximately 45 inches long, 23 inches wide, and 23 inches tall. The Solar Panel is situated 25 inches above the top of the cart. **Figure 3-3** shows a sketch of the side view of the cart. On top of the cart, there is 10 USB charging ports that are evenly spaced out. The first USB charger is spaced 3 inches from the side, and there is a USB charger every 4 inches thereafter. There is a speaker situated on top of the cart along with the TV and LCD display for the micro controller. The last addition that will be added to the cart is the light string that is connected right below the solar panel.

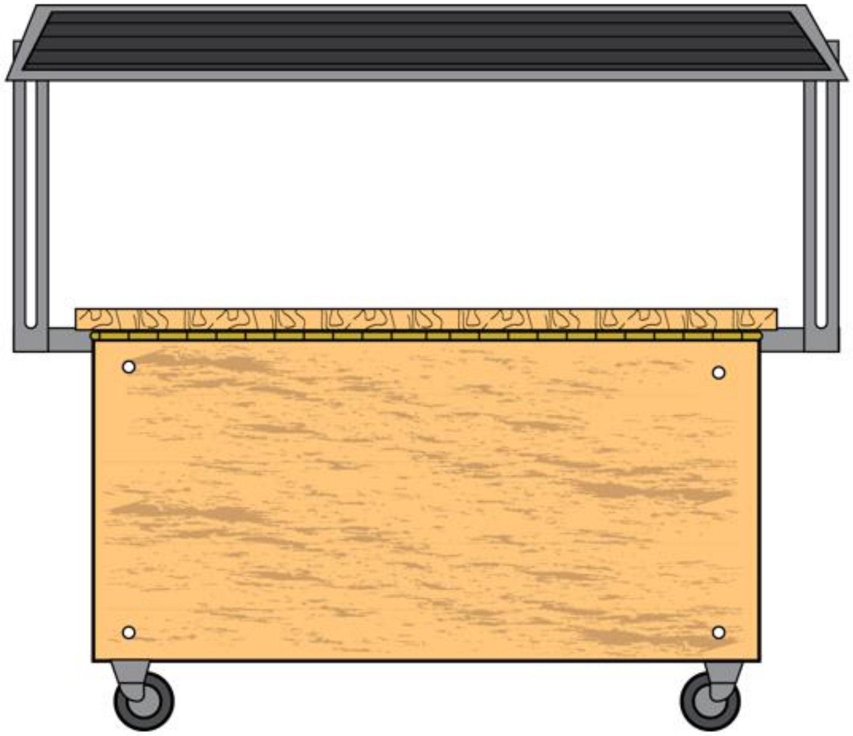

Figure 3-3. Side View of the Cart

The basic design idea behind this project starts with a Solar Panel that will charge a battery through a charge controller. The charge controller will help regulate and manage the power produced by the solar panel to be either going to the loads or charge the battery. The power will then be distributed to three separate circuits feeding 3 separate sets of loads, each with their own circuit breaker that will protect each load. Two of the loads will contain 5 USB chargers in parallel. The third load has one USB charger, the TV, and the microcontroller. Table 3-3 summarized the component specifications of the proposed solar roller system.

Table 3-3. Solar Roller Component Specifications

Specification	Implementation	Testing
USB Charging ports that supply 5V and up to 1A.	Two loads of five charging ports each (25 W maximum); each load protected by circuit breakers.	Each DC-DC buck converter tested individually to test for faults. Five working converters placed in parallel and tested with multiple devices charging. Final testing done with all loads in use (MP3 player, speakers, TV, Arduino, and 10 devices charging).
MP3 player, speakers, TV, string lights	All devices on one load with Arduino. Speakers are powered via 3.5mm jack connected to MP3 player.	MP3 is charged using another tested buck converter. Arduino is powered using a twelfth buck converter. TV powered directly from 12V load. Power monitored to ensure 25W max load.
Charge Controller	Prevents solar panel from	Battery is able to be charged

	overcharging the battery.	and deliver enough power from the battery to every load
Arduino w/ LCD	Monitors and displays battery power and current delivered to loads	Battery content can be verified by checking the voltage of the battery. Current to each load can be measured manually and verified with Arduino display.
Mobility	Needs to be easily moved by no more than two people over multiple surfaces.	Movement tested over grass, dirt, cement, gravel, carpet, tile, and any other available surfaces.

Chapter 4. Design

Solution Statement

The Solar Roller is intended to alleviate the need for small-scale energy in areas isolated from main power lines. Areas such as parks, school campuses, and other outdoor areas where people may require power for their various mobile devices are often devoid of energy options due to the difficulty and cost of supplying power to large outdoor areas.

The Solar Roller provides a mobile power hub for users who need a quick charge for their phones. Currently, the existing solution for users who need mobile power on the go are to carry USB battery packs or spare batteries. These options can be expensive for the individual, and sometimes cumbersome to carry with you all the time. Instead of relying on everyone to own and carry their own portable energy storage, Solar Rollers can service many people concurrently.

Cell phones are crucial to everyday life. Unfortunately, current cell phone batteries do not last as long as we would like. Many users have to charge their phones 1-2 times every day. When a dead phone means you cannot contact your friends or call an Uber to pick you up, a spot to quickly charge your phone is a welcome luxury.

Protection Schematic

The protection that we used with circuit breakers is shown in **Figure 4-1**. To arrive at our desired breaker size, knowing that DC breakers are approximately 80% efficient, the maximum load current was calculated and the breakers were sized at 1.25x that of maximum expected

current. We chose to have a 10A breaker before each of the three loads rather than one main breaker protecting all of the loads in order to control which loads will and won't work in case of a trip. The drawback of one main breaker is that if a trip were to occur, all of the loads would lose power and nobody would be able to charge from the ports. With a breaker on each of the loads, this allows for some of the loads to function properly if there is a trip on a different load. There is a 6A breaker between the solar panel and the charge controller, as the maximum rated current output of the panel is around 4 amps, and this is just another level of added protection to the system. The 30A breaker after the battery is there to allow the three loads to get their current requirements satisfied, while protecting against excess current leaving the battery and damaging the loads.

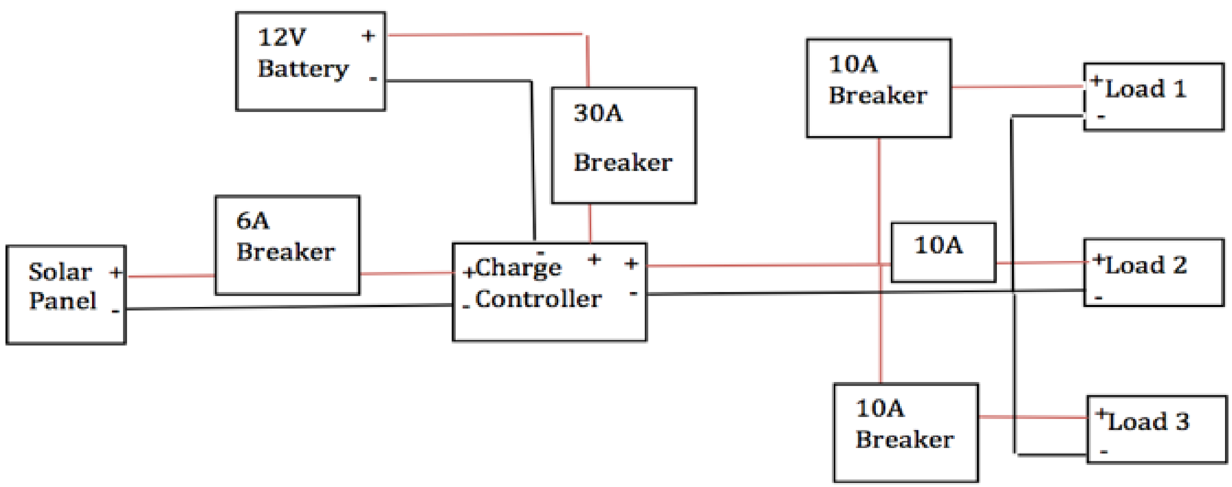

Figure 4-1. Protection Schematic

Breakers were chosen for the protection of the system rather than fuses because fuses need to be physically replaced when there is too much current flowing through them. With breakers, a simple flip of the switch can restore them to their original functionality.

We sized our breakers based on the current going to each load. For all of the calculations we used the equation for real power in DC: Power = Current * Voltage. For Load 1 and Load 2, we connected 5 Buck converters to USB in parallel. We did all of the sizing of the breakers in reference to the maximum possible ratings that the system could take. The maximum output power of the Buck converters is rated at 15W. The input voltage of the Buck converters was 12V, so assuming the Buck converter was working at a theoretical 100% efficiency, the maximum input current would be:

$$I_{inmaxeach} = \frac{15W}{12V} = 1.25A$$

Since there are 5 converters in parallel, the maximum current of the system would be

$$I_{inmaxtotal} = 1.25A \times 5 = 6.25A$$

DC Breakers are known to be around 80% efficient, so we multiplied the maximum current by 1.25 to get a total max current of the load to be 7.81A. We chose the 10A breaker because the 8A breaker would be too close, and the 10A breaker was the next available size.

For Load 3, we connected 2 USB chargers, lights, and a TV in parallel. The two USB chargers will draw a maximum of 2.5A. The lights were measured to be drawing at 0.5A. The maximum current of the TV is rated at 3A. In total, the maximum current of Load 3 is therefore:

$$I_{Load3} = 2.5A + 0.5A + 3A = 6A$$

This yields the breaker sizing of:

$$I_{breaker3} = 6A \times 1.25 = 7.5A$$

The display for the Solar Roller is designed using an Arduino Uno and an LCD screen. The screen displays the percentage of the remaining battery power. The deep-cycle battery voltage is divided between a 16kΩ and a 10kΩ resistor. From **Figure 4-2**, the range of voltages out battery will have is 11.80V to 12.85V. This means that the voltage across the 10kΩ resistor is 4.54V and 4.94V. The voltage across the 10kΩ resistor is input into the Arduino through the analog port. This value is converted by the microcontroller into a 10-bit value representing its voltage up to a maximum of 5V. For example, at 4.54V the value is:

$$1023 \cdot \frac{4.54}{5.00} = 928$$

On this scale, 920 is set as 0% battery while 1020 is set as 100%. This percentage is then written to the LCD screen.

State of Charge	Sealed or Flooded Lead Acid	Gel battery	AGM battery
100%	12.70+	12.85+	12.80+
75%	12.40	12.65	12.60
50%	12.20	12.35	12.30
25%	12.00	12.00	12.00
0%	11.80	11.80	11.80

Figure 4-2. Battery Percentage

Adding up all of the load currents maxes together, the total maximum current of the entire system from the charge controller is 23.12A. The battery chosen for the Solar Roller is

rated at 75Ah. With the battery on full charge and every device of the Solar Roller being in use, the battery should last

$$\frac{75Ah}{23.12A} = 3.24h$$

This time is assuming that the solar panel is not charging the battery while in use.

The size of the breaker on the solar panel is 6A. This is calculated based on the solar panel rating of 4.5A. Thus, multiplying it by 1.25 would yield 5.625A. A 6A breaker was the closest commercially available breaker size.

In addition of the breakers, the sizing of the wires was important. The current flowing through the system does not exceed 35A and no wire is longer than 7 feet, so a 10 gauge wire was chosen for the system. Even though the loads individually aren't meant to exceed 10A, we decided for efficiency reasons to use the 10 AWG wire in bulk and use it throughout the system. **Figure 4-3** shows how the length and current vary with wire gauge size.

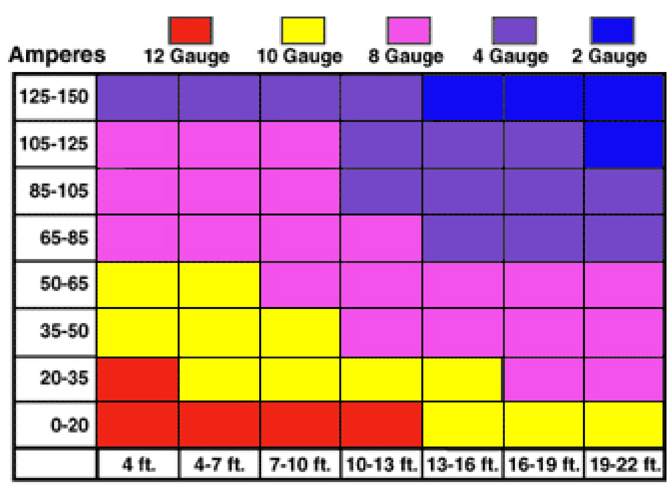

Figure 4-3. Wire Gauge Chart

Chapter 5. Hardware Test and Results

The bulk of the hardware design for the Solar Roller consisted of the overall system components, as well as the protection of the system. This included breakers and the charge controller, as well as the wiring of the system. Extensive labor was also required in the assembly of the Solar Roller. With all of the main components planned out to determine where they should go on the cart, we had to strip wires and crimp them to fit the solar panel, battery, and charge controller together, as well as the circuit breakers and various loads..

We decided to solder 24 gauge wires individually to each USB buck converter, and then connect them in parallel with larger 10 gauge wires that were able to carry the current of the whole system. Once each load of 5 USB chargers was soldered together, the positive lead could be crimped and attached to the circuit breaker. Before attaching to the circuit breaker, however, we ran a test on each port and the entire 5 USB system to test the current carrying capabilities of the load. The test was done by connecting a multimeter in series with each load to measure the current, a very simple connection. The results are shown in **Table 5-1**. The negative lead was left untouched to be tied together with all the negative leads of each load, so they would connect to the charge controller through one main negative wire. The testing of each USB port was done with 12V from a power supply, and connecting a standard micro-USB cable and checking the charging ability on a phone.

Table 5-1: Current Measurements for Each Load

	Average Current (Amps)	Peak Current (Amps)
Load 1	8.18	9.12
Load 2	8.37	9.23
Load 3	7.17	8.56

For the TV and LED lights, tests were ran with the multimeter to determine the current draw and power draw from these two loads. A multimeter was connected in series with each load, and the current was entered into **Table 5-1**.

Equipment Required for Load Testing:

- FLUKE 179 True RMS Multimeter
- Banana-to-banana lead
- Banana-to-grabber lead

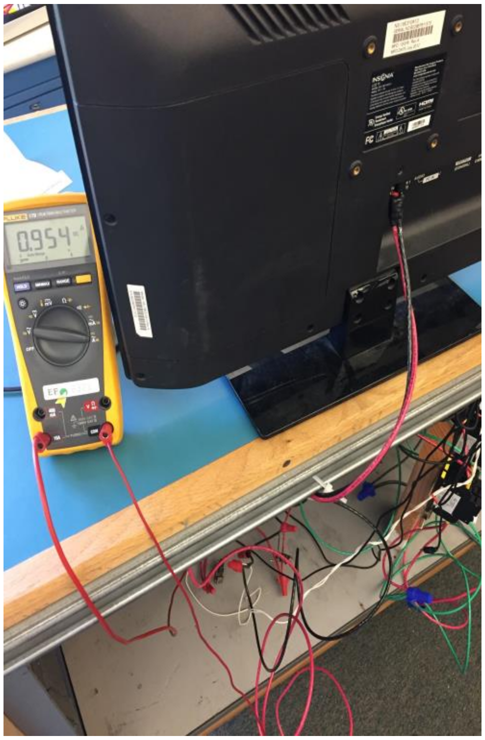

Figure 5-1: Current Drawn by TV Test Setup

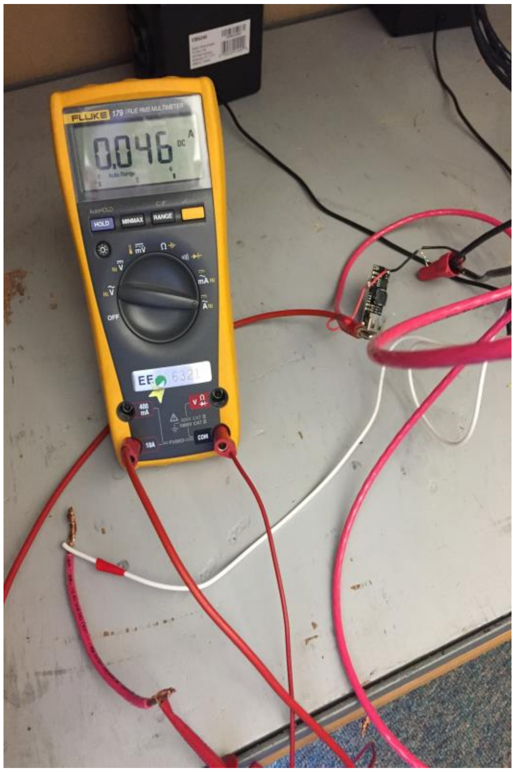

Figure 5-2: LED Light Strip Current Draw Test Setup

Table 5-2: Load Test Results

Load	Current (A)	Power (W)
LED Light Strip	0.046	0.55
DC TV	0.954	11.45

The third load is the one that varied from the other two. We used the same idea of having a 24 gauge wire connected with the 10 gauge wires in parallel for the 2 USB ports on this load. We then soldered the positive and negative ends of the LED light load in parallel. Lastly, we soldered wire to the 12V adapter for the DC TV and put that in parallel with the rest of the load. The positive wire of the entire load was attached to the last 10 Amp breaker and the negative was connected with the other two negatives of Load 1 and 2. The third load also includes the microcontroller that displays the battery percentage. The battery was connected to a voltage divider which reduced the input voltage to a value between 2 and 3 V. The input to the microcontroller is also protected by a zener diode that maintains a maximum of 5V. This voltage then corresponds to a percent charge of the battery. This was tested by inputting possible battery voltages and examining how accurately the microcontroller reported that voltage. The test bench setup is seen in **Figure 5-3.**

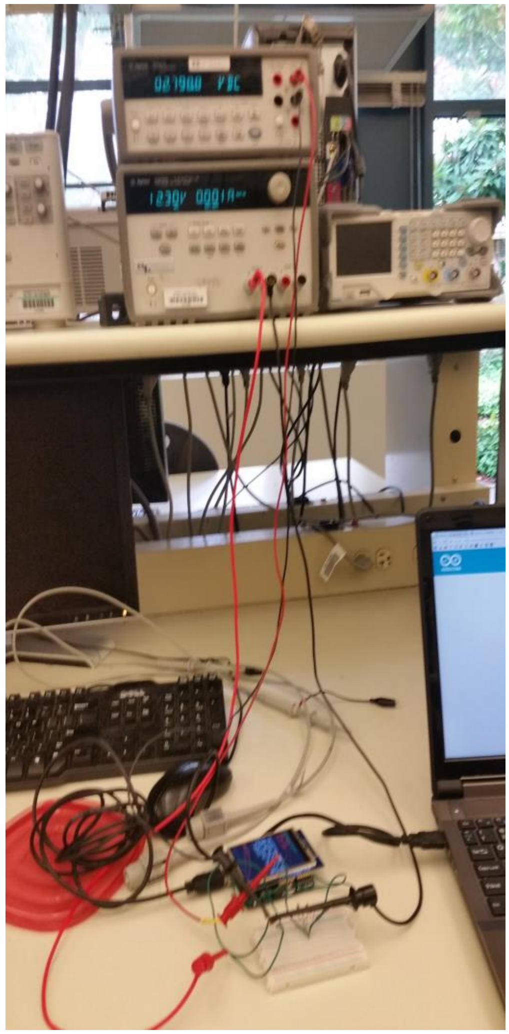

Figure 5-3: Microcontroller Test Setup

The battery is simulated by a DC power supply supplying between 11.6 and 13 V. The battery percentage is then displayed on the screen and verified by hand. The divided voltage is also measured and used to approximate the analog value that the arduino should register. The expected and measured values in **Table 5-3.**

Table 5-3: Microcontroller Battery Level Test

Battery Voltage (V)	Analog In (V)	Expected Analog Value	Expected Battery Percentage	Measured Analog Value	Measured Battery Percentage
11.6	2.7	837	EMPTY	818	EMPTY
11.7	2.72	844	0	825	0
12	2.79	866	27	846	27
12.2	2.84	880	45	859	47
12.5	2.91	902	73	879	74
12.8	2.98	924	100	898	100
13	3.02	938	FULL	911	FULL

The Expected Analog Value is calculated by dividing the analog in voltage by the reference voltage of the arduino (3.3 V) and multiplying by 1024 (the Arduino is accurate to 10 bits). The measured value differs slightly, but because the amount it differs by is consistent regardless of possible input values, it does not affect the accuracy of measuring the battery percentage. The battery percentage is calculated by finding the analog value measured when inputting 11.7 volts (a dead battery), the analog value measured when inputting 12.8 volts (a full battery), and the difference between them. The percentage of the battery is then the ratio between the difference of the input analog value and the minimum analog value (825) and the range of analog values (73).

ex. if the battery voltage is 12.2, the analog output is 859. The difference between this value and the minimum value of 825 is 34. 34 divided by 73 (the difference between maximum and minimum voltage) is 0.47. This is verified by observing the microcontroller screen read 47 % battery.

In addition to displaying the battery life, the microcontroller also displays a random fact about solar energy on the screen to educate users about solar and renewable energy impact on the environment. These facts and the Arduino code can be seen in **Appendix A.**

To test the charging capabilities of the solar panel and the charge controller, the cart was rolled into the sun as the voltage of the battery was measured. In direct sunlight with no loads active, the battery voltage slowly increased, indicating that the battery was being charged.

To test the operation of the solar panel, the cart was moved outdoors, on a sunny day where the panel had ample sunlight to generate voltage. The open circuit voltage was measured from the leads of the panel, and the results are in **Table 5-4**. The short circuit current was also measured with the multimeter, with the results shown in **Table 5-4**. These tests were made at approximately 1:30 PM in June, when the sun was very high in the sky. The nominal OC voltage and SC current were obtained from the label on the panel.

Equipment Required for Solar Panel Testing:

- FLUKE 179 True RMS Multimeter
- Banana-to-grabber leads (x2)

Figure 5-4: Open Circuit Voltage Test Setup

Figure 5-5: Short Circuit Current Test Setup

Table 5-4: Solar Panel Test Results

	Open-Circuit (Nominal)	Open-Circuit (Tested)	Short-Circuit (Nominal)	Short-Circuit (Tested)
Voltage (V)	43.5	38.6	N/A	N/A
Current (A)	N/A	N/A	4.75	4.727

As seen in Chapter 4, the loads were made sure to be connected into one positive wire and one negative wire as to fit into the charge controller. Once the connections were made and

all of the ports were given a final check, we cut the holes for the USB chargers to stick up through and glued them in. Lastly, the TV was placed on top of the cart with the speakers and touch screen, and the side panels of the cart were fastened on.

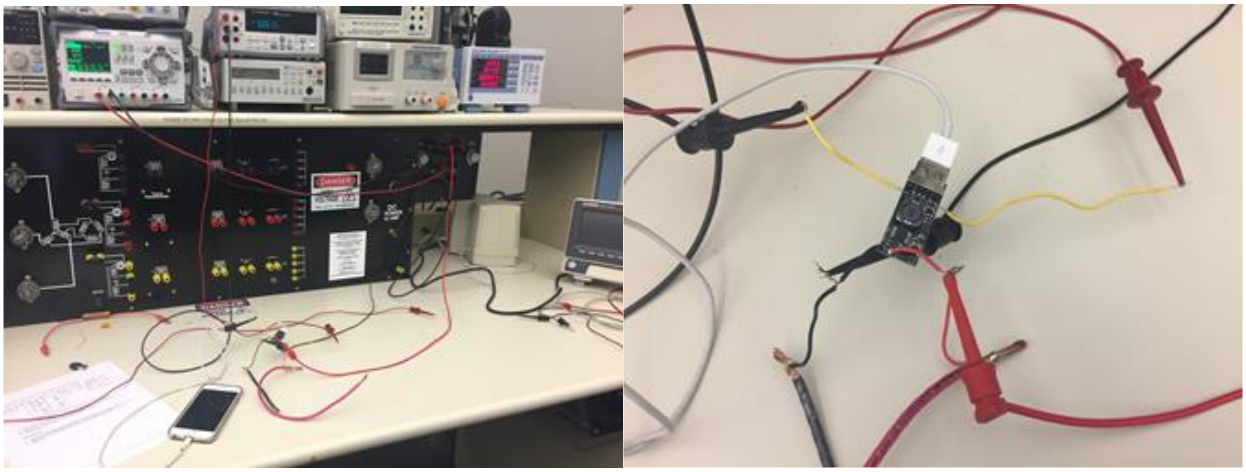

Figure 5-6: Buck Converter Testing Set Up

Figure 5-7: Output voltage Peak to Peak Ripple

For testing the buck converter, we used a DC Power Supply (Rigol DP832), a Digital Wattmeter (Yokogawa WT 330), and an Electronic Load (BK Precision). Our setup is shown in **Figure 5-6**. We tested 3 input voltages to have a high voltage, low voltage and a nominal voltage. The voltages used were 9V, 12V, and 15V. At each voltage, we tested the 4 separate load scenarios to see how the converter's efficiency changed under different loads. **Table 5-5** shows our results. From the table, it is clear that highest efficiency was at the nominal 12V that the buck converter is rated for. It is also clear that at low load, the efficiency of the converter was the highest.

Table 5-5: Buck Converter Testing Results

12V	Load Current (A)	Output Voltage (V)	Output Power (W)	Input Power (W)	Efficiency (%)
	3	4.531	13.593	18.5	73.48%
	2	4.705	9.41	11.6	81.12%
	1	4.883	4.883	5.3	92.13%
	0.5	4.903	2.4515	2.56	95.76%
9V	Load Current (A)	Output Voltage (V)	Output Power (W)	Input Power (W)	Efficiency (%)
	3	4.532	13.596	20.4	66.65%
	2	4.705	9.41	12.4	75.89%
	1	4.887	4.887	5.8	84.26%

	0.5	4.977	2.4885	2.7	92.17%

15V	Load Current (A)	Output Voltage (V)	Output Power (W)	Input Power (W)	Efficiency (%)
	3	4.545	13.635	18.3	74.51%
	2	4.702	9.404	11.6	81.07%
	1	4.881	4.881	5.4	90.39%
	0.5	4.973	2.4865	2.6	95.63%

Along with testing efficiency, we tested Load and Line Regulation and Output Peak to Peak Voltage Ripple. Load Regulation was found by taken with the following equations. The Load Regulation results were slightly larger, but the Line Regulation was minimal.

Line Regulation [%] $$\frac{\bar{V}_{out(high-input)} - \bar{V}_{out(low-input)}}{\bar{V}_{out(nominal-input)}} \times 100\%$$

Load Regulation [%] $$\frac{\bar{V}_{out(low-load)} - \bar{V}_{out(high-load)}}{\bar{V}_{out(high-load)}} \times 100\%$$

Table 5-6: Load and Line Regulation

Load Regulation	Line Regulation
8.21%	0.287%

The Output Peak to Peak Ripple results is shown in **Table 5-7** and a screenshot of the oscilloscope is shown in **Figure 5-7.** The buck converter has a very low ripple which is ideal.

Table 5-7: Output Peak to Peak Ripple for Buck Converter

Output Pk-Pk Ripple (V)	Output Pk-Pk Ripple (%)
0.00342	0.075%

Chapter 6. Conclusion

The Solar Roller was effectively able to charge an array of devices through the USB ports, as well as provide enough power to supply a TV as well as a lighting system. At full load with a fully charged battery, the Solar Roller system can run without a direct source of light for approximately 3-4 hours. This successfully satisfied our original project requirements, and exceeded expectations when it came to charging and current handling capabilities. Based on feedback and comments regarding the Solar Roller, it was concluded that this solar powered charging station is something that the general public would enjoy to use at events or festivals.

If we had more time and money to improve this project, it would be nicer to clean up the connections to the USB chargers. Due to money constraints, we used extra 10 gauge wires in connection even though a smaller 16 gauge wire would have sufficed. This would have greatly cut down on the clutter. It would have also been nice to spend more time securing all the wires and equipment in the cart. While transporting the Solar Roller currently, wires can easily come loose and come apart.

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Appendix A: Senior Project Analysis

Project Title: Solar Roller

Students: Tanner Mjelde, Kaylan, Naicker, Aaron Bartfeld

Advisor: Taufik

1. Summary of Functional Requirements
    a. Overall Capabilities
        i. The Solar Panel provides power to the USB charging ports, TV, lights, and microcontroller display
        ii. LCD screens should show how voltage level of battery
2. Primary Constraints
    a. Challenges associated with the project
        i. Designing the power distribution circuit
        ii. Implementing the microcontroller with the LCD screen
        iii. Keeping the cost reasonable
        iv. Designing protection circuitry for safe operation
3. Economic
    a. What will impact the result?
        i. Human Capital: The development of this device will create jobs in engineering, manufacturing, sales, and marketing
        ii. Financial Capital: This product is designed for an initial 50% profit on each unit.
        iii. Natural Capital: Our design is using completely renewable energy that will only benefit the environment. If the solar roller were to break completely and become useless, most of the parts are recyclable except for some of the circuitry.
        iv. Cost: The cost is very flexible because of how many different companies supply the same parts at different prices. Our goal is to get quality at the lowest price. It is very important to us that our product is quality because of the large scale of the design and the idea of self sustainability.

Table 7-1: Estimated Cost Overview

Part	Quantity	Cost
Microcontroller	1	~$30
USB Chargers	10	~$50
Cart	1	~$150
Solar Panel	1	~$200
Power Circuit	1	~$100
LCD Screen	1	~$30
Battery	1	~$100
Speakers	1	~$50

Table 7-2: Actual Cost Overview

Part	Quantity	Cost
Microcontroller	1	N/A
USB Chargers	10	$85
Cart	1	N/A
Solar Panel	1	N/A

LCD Screen	1	$25
Circuit Breakers	5	$86.65
Battery	1	$105
Speakers	1	$15

4. If manufactured on a commercial basis
    a. Expect 50 units being sold in the first year after final prototypes were made.
    b. Total cost would be around $1400 to the event planner or school
    c. Actual Manufacturing cost would be around $970. Possibly less if we produce at a large quantity and can buy parts in bulk
    d. The prices of maintaining can range from $0-$500 depending on how good the company/school takes care of the product. It should be self-sustainable due to the solar power, but people always seem to break things.
5. Environmental
    a. The main environmental impact would be positive. Manufacturing the parts could be detrimental to the environment because of the unknown facility emission laws in countries outside the United States. Once the solar roller is built and in use, there are no emissions because it essentially just a solar panel and a battery.
6. Manufacturability
    a. The Solar Roller is a large design that requires multiple parts. Individual components would have to make separately and then assembled at a later time. The solar panel to usb chargers would be done. Then the power to microcontroller to LCD screens would be done. Once both of those key electrical engineering components are made, the assembly step would take place. Everything would be correctly placed in the cart.
7. Sustainability
    a. The product life of our product should depend on the life of weakest component because it is self-sustainable.
    b. It is dependent on sunlight to power the cart, however once the battery is charged the cart can be operated without the need for sun. It has capabilities to run for 3-4 hours at full load from the fully charged battery. The time required to charge depends on irradiance from the sun, this varies for the area one lives and the time of the year it is.
8. Ethical Consideration
    a. The design is meant to be used by all and to better the environment. There are no ethical drawbacks that would harm society besides the fact that people might

spend more time on their phones than they previously did.

b. Not all of the components will be recyclable.
c. The components that we use are most likely going to be manufactured overseas where labor laws are not as strict as they are in America. We will strive to buy from companies that treat their workers well and are made in the United States.

9. Health and Safety
    a. The Solar Roller won't have an impact on the heath of user directly, but because of its renewable and clean energy reliance, it will contribute to a cleaner environment. This will in turn indirectly improve the quality of life where the Solar Roller is used.
    b. There is no gas or generator involved in the design so this will make the Solar Roller safer from possible catastrophes from those devices
10. Social and Political
    a. The usage of cellphones around the Solar Roller will increase due to the accessibility of the charging station.
11. Development
    a. Insight on protection circuitry such as breakers was gained from research throughout this project

Appendix B: Microcontroller Code

```
// IMPORTANT: Adafruit_TFTLCD LIBRARY MUST BE SPECIFICALLY
// CONFIGURED FOR EITHER THE TFT SHIELD OR THE BREAKOUT BOARD.
// SEE RELEVANT COMMENTS IN Adafruit_TFTLCD.h FOR SETUP.
//Technical support:goodtft@163.com

#include <Adafruit_GFX.h>    // Core graphics library
#include <Adafruit_TFTLCD.h> // Hardware-specific library

// The control pins for the LCD can be assigned to any digital or
// analog pins...but we'll use the analog pins as this allows us to
// double up the pins with the touch screen (see the TFT paint
example).
#define LCD_CS A3 // Chip Select goes to Analog 3
#define LCD_CD A2 // Command/Data goes to Analog 2
#define LCD_WR A1 // LCD Write goes to Analog 1
#define LCD_RD A0 // LCD Read goes to Analog 0

#define LCD_RESET A4 // Can alternately just connect to Arduino's
reset pin

// When using the BREAKOUT BOARD only, use these 8 data lines to the
LCD:
// For the Arduino Uno, Duemilanove, Diecimila, etc.:
//   D0 connects to digital pin 8  (Notice these are
//   D1 connects to digital pin 9   NOT in order!)
//   D2 connects to digital pin 2
//   D3 connects to digital pin 3
//   D4 connects to digital pin 4
//   D5 connects to digital pin 5
//   D6 connects to digital pin 6
//   D7 connects to digital pin 7
// For the Arduino Mega, use digital pins 22 through 29
// (on the 2-row header at the end of the board).

// Assign human-readable names to some common 16-bit color values:
#define    BLACK   0x0000
#define    BLUE    0x001F
#define    RED     0xF800
#define    GREEN   0x07E0
#define CYAN    0x07FF
#define MAGENTA 0xF81F
#define YELLOW  0xFFE0
#define WHITE   0xFFFF

Adafruit_TFTLCD tft(LCD_CS, LCD_CD, LCD_WR, LCD_RD, LCD_RESET);
// If using the shield, all control and data lines are fixed, and
// a simpler declaration can optionally be used:
// Adafruit_TFTLCD tft;
```

```
float volt = 0;
float convert = 0;
float per = 0;

void setup(void) {
 Serial.begin(9600);
 Serial.println(F("TFT LCD test"));

#ifdef USE_ADAFRUIT_SHIELD_PINOUT
 Serial.println(F("Using Adafruit 2.4\" TFT Arduino Shield Pinout"));
#else
 Serial.println(F("Using Adafruit 2.4\" TFT Breakout Board Pinout"));
#endif

 Serial.print("TFT size is "); Serial.print(tft.width());
Serial.print("x"); Serial.println(tft.height());

 tft.reset();

  uint16_t identifier = tft.readID();
  if(identifier == 0x9325) {
   Serial.println(F("Found ILI9325 LCD driver"));
 } else if(identifier == 0x9328) {
   Serial.println(F("Found ILI9328 LCD driver"));
 } else if(identifier == 0x4535) {
   Serial.println(F("Found LGDP4535 LCD driver"));
 }else if(identifier == 0x7575) {
   Serial.println(F("Found HX8347G LCD driver"));
 } else if(identifier == 0x9341) {
   Serial.println(F("Found ILI9341 LCD driver"));
 } else if(identifier == 0x8357) {
   Serial.println(F("Found HX8357D LCD driver"));
 } else if(identifier==0x0101)
 {
     identifier=0x9341;
      Serial.println(F("Found 0x9341 LCD driver"));
 }
 else if(identifier==0x1111)
 {
     identifier=0x9328;
      Serial.println(F("Found 0x9328 LCD driver"));
 }
 else {
   Serial.print(F("Unknown LCD driver chip: "));
   Serial.println(identifier, HEX);
   Serial.println(F("If using the Adafruit 2.8\" TFT Arduino shield,
the line:"));
   Serial.println(F("  #define USE_ADAFRUIT_SHIELD_PINOUT"));
   Serial.println(F("should appear in the library header
(Adafruit_TFT.h)."));
   Serial.println(F("If using the breakout board, it should NOT be
```

```
#defined!"));
   Serial.println(F("Also if using the breakout, double-check that all
wiring"));
   Serial.println(F("matches the tutorial."));
   identifier=0x9328;

 }
 tft.begin(identifier);


}

void loop(void) {
  tft.fillScreen(BLACK);
 unsigned long start = micros();
 tft.setCursor(0, 0);
 analogReference(EXTERNAL);
 volt = analogRead(5);
 per = 100*(volt - 825)/73;
 convert = volt*3.889/1024 *11/2.5;

 tft.println();
 tft.setTextColor(GREEN);
 tft.setTextSize(2);
 tft.println("Battery Level:");
 tft.setTextColor(RED);
 tft.setTextSize(3);

 if (per > 100)
 {
   tft.println("FULL");
 }
 else if (per < 0)
 {
   tft.println("EMPTY");
 }
 else
 {
   tft.println(per);
 }
 tft.println();
 tft.setTextColor(WHITE);
 tft.setTextSize(2);


 if (per < 20)
 {
   tft.println("California leads all");
   tft.println("states in solar");
   tft.println("energyy capacity");
   tft.println("with 18296 MW.");
   tft.println("The next highest");
```

```
    tft.println("capacity is North");
    tft.println("Carolina (3016 MW)  [SEIA].");
  }

  else if (per < 40 && per > 20)
  {
    tft.println("The first silicon");
    tft.println("solar cell was built");
    tft.println("by Bell Laboratories");
    tft.println("in 1954.");
  }

    else if (per < 60 && per > 40)
  {
    tft.println("Every kWh of solar");
    tft.println("energy avoids ");
    tft.println("emitting 1.1 pounds");
    tft.println("of CO2. [EPA]");
  }

    else if (per < 80 && per > 60)
  {
    tft.println("US solar energy");
    tft.println("consumption in 2016");
    tft.println("had the same carbon");
    tft.println("offset as 1.5");
    tft.println("billion trees.");
  }

    else if (per > 80)
  {
    tft.println("In 2017, 1 kW of");
    tft.println("solar energy costs");
    tft.println("$0.12. In 1977, 1");
    tft.println("kW of solar energy");
    tft.println("cost $77,000.       [PVinsights]");
  }

  delay(30000);

}
```