Solar-Powered Community Lamppost
*Project Proposal Feasibility Study*

Team 11: Independent

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Calvin College  
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Executive Summary

Team Independent is in the process of designing a solar-powered lamppost for use in rural communities in third-world countries where there has been a rapid growth in the number of mobile phone users but still a lack in the availability of conventional (off-the-grid) electricity. The lamppost will perform two main functions: it will provide lighting and charging for mobile devices through USB ports. The project is part of a competition among Christian colleges, sponsored by HCJB Global – a global missions organization. So far, we have designed the overall architecture of the system and have made decisions on all the major components. By the end of the school year, we intend to have a detailed description of the form and function of the entire system, including comprehensive blueprints and schematics, as well as produce a scaled-down working prototype. The power generated from the 50-Watt mono crystalline solar panel will be stored in two separate batteries, an AGM battery that will provide power for the LED bulb, and a Lithium Polymer battery array that will power the USB outlets. The charging of the batteries will be regulated by a charging controller, while the discharging process will be regulated by a distribution controller and two switched-mode power supplies, one for the USB charging and one for the LED light. The solar panel will be mounted on a 21-foot schedule-40 galvanized steel pole that will be sunk 3 feet into the ground, supported by a concrete base. Attached to the pole will be lockable units that will house cell phones while they charge and will protect the batteries from rain and theft.
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1 Introduction
This chapter introduces the project, including a description of the course, bios of the team members, and an overview of the rest of the report.

1.1 Course
Senior engineering students at Calvin College undertake a two-semester design course sequence. Students from all four engineering concentrations offered at Calvin – Electrical/Computer, Mechanical, Civil/Environmental, and Chemical – form teams of three to five students and take on a year-long project. The design project brings together engineering knowledge and skills the students have acquired throughout their study at Calvin. The project incorporates many additional skills, including project management and financial management, which help the students prepare for careers in engineering. Although many students choose projects primarily to demonstrate engineering competence and may not solve actual problems, this project is based on a real problem, and we are designing it for a real customer, HCJB Global.

1.2 Team Members
Wisdom Aiyelabowo
Wisdom Aiyelabowo is a senior mechanical engineering student from Nigeria. Over the last two summers, Wisdom has taken an engineering class in Germany and interned at Lacks Enterprises in Grand Rapids, where he still works. Wisdom plans to get a year or two of engineering experience in industry before pursuing a Masters in Engineering Management in graduate school.

Adam Card
Adam Card is a senior mechanical engineering student from Cadillac, MI. Adam grew up the son of an Army officer and intends to follow in that career path upon his graduation as part of a Combat Engineer Unit. He has completed Basic Training, Advanced Individual Training, Air Assault School, and the Leadership Development and Assessment Course over the past two summers. Adam has a strong interest in metallurgy and electrical furnace systems, and he builds knives from scrap in his spare time.

Katie McKay
Katie McKay grew up in Lisle, Illinois and came to Calvin College in 2008, where she studied Physics and Mathematics before switching to the Electrical and Computer concentration of Engineering. She will also graduate from Calvin with a major in German and minors in Physics and Mathematics. Katie has studied in Germany twice while at Calvin and would love to work there in the future. She has worked for four years as a peer tutor at Calvin, tutoring chemistry, physics, math, and engineering.
Yoofi Otabil

Yoofi Otabil is a native of Ghana, studying Electrical & Computer Engineering at Calvin College. His interest in the telecommunications field led him to participate in a summer internship program with Twisthink LLC (Holland, MI), where he had the opportunity to work with GPS technology. He hopes to further his training by enrolling in a graduate program (MA and subsequently PhD) in telecommunications. At Calvin, he works with Student Academic Services as a tutor for chemistry, physics, mathematics, and engineering courses. He also has a passion to see the principles of God's kingdom being lived out and actively seeks opportunities where he can serve.

1.3 Overview of the Report

The remainder of this report consists of eight chapters. Chapter 2 defines the problem our design intends to solve. It describes the need that prompted this project, gives an introduction of the customer, HCJB Global, and outlines the objectives and requirements for the project. Chapter 3 deals with the project management, including the division of work among the team members and the team’s schedule. Chapter 4 gives an overview of the entire system. It includes physical and electrical requirements, as well as a description of the system architecture. Chapter 5 goes into detail on every component of the system, describing the requirements, the alternatives, and the decision of which alternative is best, as well as the intended implementation of components. Chapter 6 presents the economic aspects of the project. It discusses the finances for both the production of the product by HCJB and the use of the product by the proprietor. Chapter 7 summarizes the progress on the project so far and describes the work remaining to do in the following semester. Chapter 8 contains the sources we have used in our research, and Chapter 9 acknowledges all of the people who have helped to make this project a success.
2 Problem Definition

This chapter provides information about the need that prompted this project, the customer, and the reason we chose this project.

2.1 Need

Rural communities in Africa, South America, and other parts of the world have limited access to conventional power. Portable generator carts, the common alternative, are expensive to acquire and operate (some charge as much as $40 per kilowatt hour). However, the lack of accessible power has not prevented the increase of mobile phone users. In Ghana, for example, about 70% of the population are active mobile phone users, whereas just about 20% of its population have direct access to electricity. In many of these communities, sunshine is an abundant local resource. With the exception of northern and southern parts of Africa, much of the continent experiences about 8 - 10 sunlight hours per day, which makes it a good location for harvesting solar energy. The map shown below in Figure 1 shows the average number of sunshine hours in Africa and the rest of the world.

![Average yearly total number of hours of bright sunshine](http://mediawiki.middlebury.edu/wiki/OpenSourceLearning/Solar_Power#cite_note-15)

Figure 1: Average yearly total number of hours of sunshine

---

2.2 Customer
HCJB Global\textsuperscript{2} is a non-denominational, non-profit, evangelical missionary organization that reaches out to people all over the world through both media and healthcare. HCJB Global promotes healthcare by overseeing hospitals and healthcare facilities around the world, as well as developing medical and clean water missions in rural communities and providing emergency medical treatment after natural disasters. HCJB Global’s media ministry includes radio broadcasts and installation of radio stations used to communicate with people beyond the reach of traditional missionaries. HCJB is looking to add solar-powered community lampposts to its outreach. It has proposed a design competition among Christian colleges to develop this solar-powered community lamppost with portable device charging capabilities. This lamppost will not only provide a service that is needed, but it will also require a proprietor, and it can be the basis for a small business in the community. HCJB is looking into the possibility of installing these lampposts next to wells that they have already installed in rural communities around the world.

2.3 Project Choice
The team chose this project primarily because of the opportunity to work with renewable energy sources. We recognize that renewable energy has the potential to provide an efficient and sustainable solution to global energy needs. We are also very much interested in being stewards of God’s world, and renewable energy is one way we can contribute to that. The team is also interested in caring for others. We believe that if we are in a position to improve the quality of life of others, we should. As a result of this project, we are able to help HCJB by providing labor at a much lower cost, and we are also able to help rural communities in Africa and South America.

\textsuperscript{2} \textit{http://www hcjb.org/}


3 Project Management

This chapter describes the structure of the team and the duties of each team member. It also describes the work breakdown schedule for the entire project.

3.1 Team Management

The team consists of two mechanical and two electrical engineering students. Wisdom Aiyelabowo is responsible for researching and deciding on the batteries and the solar panel. He is also involved with analyzing the thermodynamics of the system – ensuring that all components are with operating temperature requirements. Wisdom also ensures that the team is on schedule with all meetings and deadlines. Adam Card is in charge of research on lighting source options. Because of his interest in metallurgy, he is also involved with the structural analysis of the mechanical components of the lamppost. Adam makes sure that the weekly status reports are sent out to Professor VanderLeest. Katie McKay is in charge of drawing up an operational and production budget. She is also in charge of ensuring that all components of the system are operating at optimum power requirements. Her research on super capacitors as an alternate energy storage device was used to make a decision on a suitable energy storage device. Katie also takes notes during all team meetings. Yoofi Otabil is in charge of research on the charging controller, USB charging of mobile devices, the ambient light sensor, and on the microcontroller that will enable the user configure the system. He is also responsible for updating the team’s project website (http://www.calvin.edu/academic/engineering/2012-13-team11/index.html) and posters.

The team meets weekly to work on the project and ensure that all goals are being met as required. We report to the team advisor, Professor Steven VanderLeest of the Calvin College Engineering Department, and our industrial liaison, Scott McConnell of HCJB. They give weekly feedback on reports of the team’s projects, as well as suggestions that the team could look into.

3.2 Schedule

In order to ensure that the team works at a healthy pace over the course of the year, we developed a work breakdown schedule. A link to the work breakdown schedule can be found here (http://www.calvin.edu/academic/engineering/2012-13-team11/docs/WBS.pod). Table 1 is a summary of the work breakdown schedule that highlights the tasks that have been completed and current progress of the project.
<table>
<thead>
<tr>
<th>PROJECT MILESTONES</th>
<th>DURATION (hr)</th>
<th>ACTUAL DURATION (hr)</th>
<th>COMPLETION (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define Project Objectives</td>
<td>9</td>
<td>9</td>
<td>100</td>
</tr>
<tr>
<td>Define system components</td>
<td>12</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>Consult</td>
<td>4 + 2(weekly)</td>
<td>4 + 2(weekly)</td>
<td>100</td>
</tr>
<tr>
<td>Economics Management</td>
<td>17</td>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>Generate Component Alternatives</td>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Select system components/Purchase</td>
<td>20</td>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>Model, Testing and Debugging</td>
<td>296</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Build Prototype</td>
<td>40</td>
<td>Not Started</td>
<td>0</td>
</tr>
<tr>
<td>Reports</td>
<td>110</td>
<td>50</td>
<td>45</td>
</tr>
<tr>
<td>Design Presentation</td>
<td>10</td>
<td>Not Started</td>
<td>0</td>
</tr>
</tbody>
</table>

The team spent less time than anticipated on developing an economic management plan because HCJB bears majority of the responsibility of developing a financial strategy for the product.

One of the primary goals for the team for this semester is to make decisions on all major system components and order the parts by the end of the semester. At this point, the team has chosen and ordered the solar panel, batteries, charging controller, switched-mode power supplies, LCD screen, USB outlet ports, LED light bulb, and some acrylic for use in the physical structure. Our goal for the entire year is to produce a full set of electrical circuit schematics, a detailed description of the mechanical structure, and a fully working scaled-down prototype of the lamppost. We chose to scale down the prototype to increase the mobility of the unit and to ensure that the project falls within its financial budget.
4 System Architecture

This chapter explores the system as a whole (both the mechanical and electrical components). It begins by presenting the objectives of the project and the requirements for each part of the system that were provided by HCJB Global, and then it describes the architecture of the entire system.

4.1 Objectives

These are our objectives for this project:

1. Design a solar-powered lamppost with charging ports for electronic devices to be used in remote locations.
2. Provide security for devices while they are charging.
3. Manage power so that there is enough energy to power light at night

4.2 Requirements/Specifications

4.2.1 Customer Priority Rubric.

Table 2 shows the priority rubric provided by HCJB Global to help our design team understand the relative importance of different aspects of the project.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability/ruggedness</td>
<td>20%</td>
</tr>
<tr>
<td>Meets or exceeds project specifications</td>
<td>20%</td>
</tr>
<tr>
<td>Operating time to 50% light output without sunlight</td>
<td>20%</td>
</tr>
<tr>
<td>Ease of manufacture</td>
<td>10%</td>
</tr>
<tr>
<td>Cost</td>
<td>10%</td>
</tr>
</tbody>
</table>

4.2.2 Physical Requirements

HCJB Global also provided the following requirements for the mechanical infrastructure.

*Note: To decrease transportation costs, HCJB plans to obtain the steel pole at the location where the lamppost will be installed.*

1. The structure must use a galvanized steel pole 15 to 21 feet long.
2. The pole must be sunk 3 feet into the ground.
3. The pole must have a 1.5-inch nominal diameter.
4. The pole must be Schedule 40.
5. The entire system must be able to withstand temperatures from 0° F to 130° F.
6. The structure must remain intact with wind gusts up to 60 mph and sustained winds of 40 mph.
7. The structure must be weatherproof.
8. The structure must be durable and require little maintenance.
4.2.3 Electrical Requirements

HCJB Global provided the following electrical requirements for the system.

1. The system must be able to store enough energy for two days of operation with no sunlight.
2. The system must provide at least 10 hours of light per night.
3. The system must provide two USB charging positions with USB type A ports, running 0.5 Amps at 5 Volts.
4. The system must be able to turn itself on at night.
5. The proprietor must have the ability to program the number of hours the light will be on, 1 to 10 hours with 1-hour resolution.
6. The system must include current limiting and short circuit protection.

4.3 System Design

This project can be divided into three subsystems: the mechanical infrastructure, the electrical system, and the electrical control, as shown in Figure 2. Some components, such as the solar panel, are included in both the mechanical infrastructure and the electrical system, because they have both mechanical and electrical aspects in the system.

4.3.1 Mechanical Infrastructure

The mechanical infrastructure consists of the pole, the solar panel, the LED light source, and the enclosure which contains both the charging ports and many of the electrical components, as shown in Figure 3. The CAD drawing in Figure 4 shows a preliminary design for the mechanical structure of the system.
Figure 3: Mechanical Structure

Figure 4: CAD model of lamppost
More details on the mechanical infrastructure are discussed in Section 5.8.

4.3.2 Main Electrical System

The main components of the electrical system are the solar panel, the energy storage elements, the LED light source, and the USB outlets. Other necessary elements are voltage regulators, controllers, and short-circuit protection. The electrical control system also has a low-light sensor, an LCD screen, and a control knob that enables the operator to set how long the light stays on. The controllers and their associated components will be discussed in the next section. The components of the main electrical system are shown in Figure 5. More information on the individual components (the solar panel, batteries, USB outlets, and LED light source) can be found in Sections 5.1, 5.4, 5.5, and 5.6, respectively.

![Figure 5: Main Electrical System](image)

There were two options for the structure of the electrical system. Option A was to have a single energy storage device that would provide power to both the USB outlets and the light source. Option B was to have two separate energy storage devices, one for the USB outlets and one for the light source. Option A has the advantage of requiring only one set of energy storage devices, but it requires additional software. The danger with only one energy storage device is that the proprietor may charge too many devices to charge per day, leaving little or no energy to run the light throughout the night. If we chose this system, we would require our microcontroller to measure the remaining charge in the battery and then deny charging capabilities to ensure the light could run all night. Since the voltage across the battery varies with temperature, estimating the remaining charge in the battery would be very complicated. Option B eliminates the need for this battery monitoring by using two separate energy storage systems. The USB charging ports would have access to only one storage device, and the LED bulb would have access to the other. Table 3 shows the decision matrix for these two options.
Table 3: Energy System Decision Matrix

<table>
<thead>
<tr>
<th>Criteria (Score)</th>
<th>Option A</th>
<th>Option B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Components Needed</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>(40)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Software Complexity (60)</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>70</td>
</tr>
</tbody>
</table>

The decision matrix shows that Option B is preferable to Option A for this system. As a result, we decided to go with two different energy storage devices, one to supply power to the light source and one to supply power to the USB charging ports. Figure 6 shows a block diagram for the flow of energy through the system.

Additionally, the system requires voltage converters between the major components of the electrical system. The batteries output different voltages than what the USB charging ports and the LED light source require. More information on the voltage converters can be found in Section 5.3.2. Figure 7 shows a detailed block diagram of the entire electrical system.
4.3.3 Electrical Control
The electrical system contains two control elements: a charging controller, which manages the transfer of power from the solar panel to the batteries, and a distribution controller, which manages the transfer of power from the batteries to the outputs. The functions performed by each controller are shown in Figure 8.
The charging controller is located between the solar panel and the two batteries. It performs maximum power point tracking, which adjusts the output of the solar panel so that the maximum power is obtained. It also performs temperature compensation for the charging, as well as provides nighttime protection. It prevents the batteries from overcharging as well. More information on the charging controller can be found in Section 5.2.

The distribution control subsystem consists of the distribution controller and the two voltage regulators, or switched-mode power supplies, which convert the voltage output from the batteries to the voltage required by the USB outlets and the LED light source. The distribution controller performs three main functions: preventing the batteries from over-discharging, detecting the light level to turn the LED light source on, and keeping a timer to turn off the LED bulb after the specified time has elapsed. More information on the distribution control can be found in Section 5.3.

Figure 8: Electrical Control
5 Components

This chapter describes each component of the system, including the requirements for the component, the alternatives we looked at, and the decision we made. For some of the components, there is also a description of how we plan to implement the component in our design.

5.1 Solar Panel

5.1.1 Requirements

The most important requirement for the solar panel is that it must be able to produce at least 350Wh daily. The team decided to go with two battery banks for the system, which will be further discussed later. In this system, one battery bank will provide energy for the USB charging (100Wh) while the other will provide for the LED lighting (250Wh). The team will use charging controllers to split the output from the solar panel between the batteries based on energy demands for each bank. Furthermore, from the buckling calculation (found in Section 5.7.3), the solar panel and other components on the pole must not exceed 492 lbs. to prevent failure of the pole. The buckling calculations were done using pole dimensions specified by the customer. With given pole dimensions, the team calculated the maximum allowable force on the pole before it buckles. Further analysis on the structure of the system will be discussed in the system structure subsection (5.7). Additional requirements for the solar panel are as follows: The solar panel must be reasonably robust to withstand harsh weather conditions as well as handling during transportation. Additionally, the solar panels must come with pre-drilled holes to ensure ease of mounting to the frame as well as to lower the assembly cost of the system. If possible, the solar panel should be durable and be designed to charge 12V batteries.

5.1.2 Alternatives

As we learned from our discussion with Michael Walma, the director of engineering from Sound Off Signals, the two main types of solar panels are crystalline and amorphous. Crystalline solar panels have silicon surfaces that are either cut or melted and poured into a mold for surfacing of the panel. On the other hand, though amorphous solar panels also have a silicon surface, they differ on the atomic level. Amorphous solar panels have irregular atomic structures on their silicon surface, while crystalline solar panels have regular atomic arrangements. The advantage of the irregular arrangement on amorphous panels is that the panel is able to absorb more light. Both types of panels could be acquired at output capacities that satisfy the system demand, but other factors were also considered to make the final decision.

First, we considered the price of the solar panel. The team looked for 50W solar panels in the two categories from different vendors. Eventually, we found a vendor selling a crystalline solar panel that would meet system demands at approximately $200. Conversely, the cheapest we could find a 50W amorphous solar panel was $300. The price variation was very evident and made our decision almost automatic. The major contributing factors to the difference in prices are that amorphous solar panels are not demanded much and they are fairly new to the industry. Next, we considered the ease of installing the solar panels. Research showed that amorphous solar panels generally need additional mounting rails for installation. This need increases both the cost and time of installing the solar panel. With the need for additional mounting rails came the need for additional space for installation.

Because stewardship is a design norm we are focusing on, we looked into environmental impacts the solar panels could have. We found out that Cadmium Telluride is used in the production of amorphous solar panels. Cadmium tends to accumulate in plant and animal tissues, and in the long run could be hazardous to their health. Though we are not faced with the threat of this pollution while the solar panel is functioning, the team looked further down the road to when the panel has reached the end of its life and must be disposed of.
With regards to the performance of the solar panels, research showed that crystalline solar panels are more efficient than amorphous solar panels; crystalline solar panels convert 17% to 25% of sunlight to electricity, while their amorphous counterparts convert about 7%. This revelation was a key factor in determining the type of solar panel we choose for the lamppost, since efficiency is very important. Finally, with regards to durability of the solar panels, research did not bear much fruit in giving specifics about the capabilities of the panels. The crystalline panels are often favored with regards to durability because they have been on the market for a while and have withstood conditions as harsh as space travel. However, the amorphous panel’s durability cannot be overlooked, as its flexibility and possible bulletproof characteristics contribute to its durability.

5.1.3 Decision

<table>
<thead>
<tr>
<th>Criteria (score)</th>
<th>Mono crystalline</th>
<th>Amorphous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (25)</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>Ease of Installation (20)</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Required Space (10)</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>General Performance (30)</td>
<td>26</td>
<td>28</td>
</tr>
<tr>
<td>Durability (10)</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Environmental Concerns (5)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Total Score (100)</td>
<td>89</td>
<td>76</td>
</tr>
</tbody>
</table>

From the decision matrix shown in Table 4, it is evident the crystalline solar panel is the most feasible for this system.

The decision of which brand of crystalline solar panel to purchase was a significant decision that necessitated a professional suggestion. The team got in contact with Ameresco, one of the largest independent energy services company in North America. We communicated Garrett Hoffman, from Ameresco solar, for his opinion on a suitable solar panel for our project. Of the numerous brand options we considered, including Sharp, LG Electronics, and Morningstar, he recommended the Value Line Solar (VLS) brand. This was mainly because this solar panel was comparatively cheap and did not have excess properties that were unnecessary for this project. Table 5 contains key properties of the selected solar panel.

<table>
<thead>
<tr>
<th>Model</th>
<th>VLS-50W</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pm(Wp)</td>
<td>50</td>
</tr>
<tr>
<td>Vmpp(V)</td>
<td>18</td>
</tr>
<tr>
<td>Impp(A)</td>
<td>2.78</td>
</tr>
<tr>
<td>Voc(V)</td>
<td>22.3</td>
</tr>
<tr>
<td>Isc(A)</td>
<td>3.03</td>
</tr>
<tr>
<td>Price</td>
<td>$200</td>
</tr>
</tbody>
</table>
5.2 Charging Controller

The charging controller is basically a voltage and current regulator to keep the batteries from overcharging. This project requires a solar charge controller because, although the nominal voltage of the panel is 12V, it is likely to output about 17V, since most panels are designed to ensure that the panel will still be able to output a voltage high enough to charge the battery even when the sun is low in the sky or there are hazy conditions, cloud cover, or high temperatures.

To successfully charge two independent batteries, the system requires either two charging controllers or a single charging controller that is able to charge two batteries simultaneously. The decision process for using one or two controllers will be discussed in Section 5.2.2. The connection between the controller and the battery is shown below in Figure 9:

![Figure 9: Charge Controller Connections](http://www.wholesalesolar.com/pdf.folder/controller%20pdf%20folder/Sunkeeper.pdf)

5.2.1 Requirements

The requirements for the charging controller are described below:

a. Temperature Compensation

Although rechargeable batteries can operate in a wide temperature range, performance varies at extreme low or high temperatures. For our applications, we are most concerned about the charging of the battery at high temperatures. Adding temperature compensation is able to prolong battery life to up to 15 percent.
Since the voltage threshold drops as temperature increases, the charging of the battery must be adjusted so as to compensate for the drop.

Table 6 shows the recommended voltage limits when recharging and maintaining a stationary lead acid battery on float charge.

<table>
<thead>
<tr>
<th>Battery Status</th>
<th>0°C (32°F)</th>
<th>25°C (77°F)</th>
<th>40°C (104°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage limit on recharge</td>
<td>2.55V/cell</td>
<td>2.45V/cell</td>
<td>2.35V/cell</td>
</tr>
<tr>
<td>Float voltage at full charge</td>
<td>2.35V/cell or lower</td>
<td>2.30V/cell or lower</td>
<td>2.25V/cell or lower</td>
</tr>
</tbody>
</table>

Table 6: Voltage Limits for Recharging a Lead Acid Battery

To show the trend in efficiency, a chart showing the efficiency of a comparable battery (NiCd) is shown below in Figure 10.

Figure 10: NiCd charge acceptance as a function of temperature

It is evident from Figure 10 that the charge acceptance is reduced at high temperatures. To compensate for this reduction, the charge controller shall have a built-in temperature sensor to detect outside temperatures and adjust charging accordingly.

b. Maximum Power Point Tracking

Maximum Power Point Tracking (MPPT) is a technique that maximizes the output from a solar panel to optimize the charging of a battery. Because the solar panel receives varying amounts of sunlight throughout the day, the charge controller controls the current and voltage output to ensure the maximum power to charge the battery. Figure 11 shows how a maximum power point is read on an IV curve.

---

The controller must periodically check for nighttime conditions (dark or cloudy weather) and be able to compensate for such conditions (when output from the solar array is minimal) by preventing reverse current leakage. We want this function because reverse leakage current causes a slight discharge from the battery. If the charging controller is able to do this, an external blocking diode will not be required.

5.2.2 Alternatives
The team narrowed down the alternatives based on the manufacturer. We realized that Morningstar had the most accessible information about their controllers, so we focused our efforts on deciding between the different charging controllers they have in production. The second criterion we used to narrow down our selection was the price of the controller. With our budget, we are willing to spend up to $150 for a controller that is able to charge two independent batteries simultaneously or up to $50 for a single controller designed to control one battery (thus requiring two such units for our application).

http://solarpowerplanetearth.com/solarchargecontrollers.html
a. Morningstar SunKeeper-6
   This controller has a small form factor and is most suited for small solar power applications like this project.

   Full description and datasheet can be found [here](#).

b. Morningstar SunSaver-10
   This controller has the ability to manage loads as well as the charging of batteries.

   Full description and datasheet can be found [here](#).

c. Morningstar SunSaver Duo
   This controller is able to charge two separate and isolated batteries at the same time, based on user selectable priorities.

   Full description and datasheet can be found [here](#).

d. Morningstar SunGuard
   This has the same circuit as the SunSaver but with less expensive packaging to provide an economical controller for small PV systems.

   Full description and datasheet can be found [here](#).

As an optional requirement, the controller shall be able to provide some feedback to the proprietor on the status of the battery and the solar panel.

5.2.3 Decision
The decision of whether to utilize two charging controllers or a single controller that is able to charge two batteries simultaneously was based primarily on the price of the two alternatives. Among the alternatives from Morningstar, we concluded that it would be a more economically sound decision to go with two charging controllers. The decision matrix in Table 7 shows our decision-making process.

<table>
<thead>
<tr>
<th>Controller/Requirements</th>
<th>Temp. Compensation</th>
<th>MPPT</th>
<th>Night Protection</th>
<th>Feedback</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>SunKeeper</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>$45</td>
</tr>
<tr>
<td>SunSaver</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>$39</td>
</tr>
<tr>
<td>SunSaver Duo</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>$134</td>
</tr>
<tr>
<td>SunGuard</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>$27</td>
</tr>
</tbody>
</table>
5.3 Distribution Control

The distribution control consists of both the distribution controller and the voltage regulation between the batteries and the loads.

5.3.1 Distribution Controller

5.3.1.1 Requirements

a. Low light sensing and control of LED light source

The most important function of the distribution controller is to turn on and off the LED light. It must detect the ambient light level and turn on the LED light when the light level drops below a certain threshold, which we will specify. The controller must then turn off the LED light after a certain amount of time, specified by the proprietor. The light does not need to stay on all night, so the proprietor shall be able to tell the light to turn off at a certain time when the light is not needed anymore, even if the proprietor is not there at the time. The controller shall also include manual overrides to turn the light on and off. For example, the light may turn on during the day because of a storm, and the proprietor shall be able to turn the light back off when it becomes bright again.

b. Prevent over-discharging of batteries

The second important function of the distribution controller is to prevent the batteries from discharging below the recommended level. For both the AGM battery and the Lithium Polymer batteries, there is a level of charge below which they are not meant to discharge. If the batteries are discharged below those levels, they will degrade and lose their ability to be fully charged. The AGM battery has a maximum voltage of 12V, and it should not be discharged below 10.5V. Each Lithium Polymer battery consists of three cells, each of which has a maximum voltage of 3.7V and should not be discharged below 3V. Therefore, each battery should not be discharged below 9V (since the cells are in series within the battery). Since the Lithium Polymer batteries will be used in parallel, the array of batteries should not be discharged below 9V. The distribution controller must be able to keep track of the voltage across the batteries and stop the discharging if their voltage drops below the specified level.

5.3.1.2 Alternatives

Because the team already has experience with the Arduino development kits, and the Arduino has a support library that is largely accessible, the decision to go with an Arduino was automatic. However, the decision between the different models took some comparison between the features offered and the features we needed. The decision matrix between the Arduino models is shown below in Table 8.

<table>
<thead>
<tr>
<th>Arduino Model</th>
<th>Microcontroller</th>
<th>Input Voltage Limits</th>
<th>Digital I/O Pins</th>
<th>Analog Input Pins</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arduino Uno</td>
<td>ATmega328</td>
<td>6 – 20V</td>
<td>14 (6 PWM)</td>
<td>6</td>
<td>$26.4</td>
</tr>
<tr>
<td>Arduino Due</td>
<td>AT91SAM3X8E</td>
<td>6 – 20V</td>
<td>54 (12 PWM)</td>
<td>12</td>
<td>$45.73</td>
</tr>
<tr>
<td>Arduino Mega 2560</td>
<td>ATmega2560</td>
<td>6 – 20V</td>
<td>54 (12 PWM)</td>
<td>16</td>
<td>$50.57</td>
</tr>
</tbody>
</table>
For the functions performed by the Arduino, an input voltage of about 12V, 5 digital output pins, and 4 analog input pins are required. Since all three models meet the design requirements, the selection of an Arduino controller was based primarily on the price point.

5.3.1.3 Decision
The team decided to go with the Arduino Uno because it met the design requirements and offered the lowest price point. A detailed specification for the Arduino Uno can be found here.

5.3.1.4 Implementation
The distribution controller will use a photoresistor to detect the ambient light level. When the light level drops below a certain level, which we will determine in our testing, the controller will turn on the LED light source. There will also be a knob for the proprietor to use to program how long the light shall stay on. The proprietor will be able to set the on-time between one and ten hours, with one hour resolution. The controller will use the amount of time given on the knob at the time it turns on as its on-time for that night, and it will turn the light off after that amount of time. Additionally, there will be a manual override ON switch and a manual override OFF switch. If the proprietor flips one of the manual override switches, the light will be forced on or off, regardless of the ambient light level or how much time is left in the on-time. Next semester, the team will determine the algorithm to do this. We will then write the code to implement this algorithm.

The low light sensing will work as follows: The photoresistor will be connected to the power supply and a pull-down resistor, as shown in Figure 12. The analog input of the Arduino distribution controller will measure the voltage across the pull-down resistor and use that value to determine the light level. Next semester we will do some testing with the photoresistor and the Arduino to determine what voltage level is appropriate as a threshold voltage to signal the light to turn on. Additionally, we will need to pick a suitable value for the pull-down resistor. The larger the pull-down resistor, the better it will measure differences in low light, and the smaller the pull-down resistor, the better it will measure differences in bright light.

![Photoresistor Setup](http://learn.adafruit.com/photocells/using-a-photocell)

Similarly to the way it will detect the voltage across the pull-down resistor to determine the ambient light level, the Arduino distribution controller will also monitor the voltage across each set of batteries. It will
continually check the voltage across the battery against the minimum allowed voltage, and if the battery voltage drops below that minimum allowed voltage, the distribution controller will disconnect the battery so that it cannot discharge any more until it has recharged. The distribution controller will then monitor the battery voltage level and reconnect it when the voltage level rises again to an acceptable level.

5.3.2 Voltage Regulation

5.3.2.1 Requirements
Since both batteries operate at different voltages than the voltages required for their outputs, the system requires voltage regulation between each battery and its output. The AGM battery, which provides power to the LED light source, operates with about 1.7A at a voltage between 10.5V to 12V, and the LED light source operates with about 700mA at 12V. For optimum performance of the LED light source, a voltage regulator must be put between the battery output and the LED input. Additionally, the Lithium Polymer batteries operate from with about 220mA at a voltage between 9V and 11.1V. The USB charging outlets require 500mA at 5V each, which gives a total of 1A at 5V, since they will be arranged in parallel. Therefore, the system requires a voltage regulator between the Lithium Polymer batteries and the USB charging outlets.

5.3.2.2 Alternatives
There are two main types of voltage regulators available: the linear regulator and the switching regulator or switched-mode power supply (SMPS). A linear regulator simply uses a reverse-biased transistor or Zener diode to cut off the voltage at the desired level. Linear regulators are quite simple to implement; a simple linear regulator circuit diagram is shown in Figure 13. A linear regulator can only decrease a voltage; it cannot increase a voltage, so the source voltage must always be higher than the load voltage. Additionally, linear regulators do not increase the current as they decrease the voltage; as a result, they lose a large amount of power that is dissipated to heat. A linear regulator typically has an efficiency of about 30% to 40%.

A switched-mode power supply has more complex circuitry than a linear regulator does. It uses combinations of energy storage elements (inductors and capacitors) and switching elements (transistors) to manipulate the input current and voltage to the desired output current and voltage. Because the voltage across an inductor is proportional to the derivative of the current, the output voltage can be greater than the input voltage of a switched-mode power supply, unlike a linear regulator. Additionally, the switched-mode power supply is much more efficient than the linear regulator. A typical efficiency for a switched-mode power supply is about 85%.

---

7 http://upload.wikimedia.org/wikipedia/commons/9/92/Zener_reg.gif
5.3.2.3 Decision

Table 9 shows a decision matrix for the voltage regulation.

<table>
<thead>
<tr>
<th>Criteria (score)</th>
<th>Linear Regulator</th>
<th>SMPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (10)</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Efficiency (30)</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Heat (30)</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Complexity (10)</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Able to increase voltage (20)</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Total Score (100)</td>
<td>26</td>
<td>80</td>
</tr>
</tbody>
</table>

Both efficiency and heat loss are very important in this project. Efficiency is very important for two reasons. First, stewardship is one of the design norms the team is focusing on, and a more efficient system does not waste as much power. Secondly, less power loss means that the solar panel does not need to provide as much energy, so it does not need to be as large. A smaller solar panel is desirable for two reasons: it is less costly, and it will be affected less by wind, which will increase the physical strength of the system. Heat loss is important, because the system is designed for a hot climate, and temperature is a major concern. Furthermore, it is preferable, although not necessary, that the voltage regulator be able to increase the voltage. This is not necessary for the regulator going to the USB charging ports, since the Lithium Polymer battery voltage will always be higher than the USB voltage. However, the AGM battery voltage may drop as low as 10.5V, which is lower than the 12V used by the LED light source. Clearly, the switched-mode power supply is superior to the linear regulator in the most important aspects, so we chose the switched-mode power supply to supply power to both the LED light array and the USB charging ports.

5.3.2.4 Implementation

For our prototype, we chose the following two switched-mode power supplies:

1. To supply power to USB charging stations: Mean Well NSD05-12S5 

2. To supply power to LED light source: Mean Well SCW08A-12

Both components are RoHS compliant, which supports our focus on stewardship as a design norm. Also, both components contain short circuit protection, which was a requirement given by HCJB Global. There are many more switched-mode power supplies available that we did not consider for our prototype because they were surface-mounted. We wanted to use components for our prototype that we are able to assemble ourselves. Next semester we may look at the surface-mounted switched-mode power supplies and possibly include different ones in our final design than the ones we are using in our prototype. It is possible that we could come up with a more cost-effective design that way.
5.4 Energy Storage

5.4.1 Requirements

According to the requirements provided to us by HCJB, the energy storage component must accommodate a total of 150Wh of energy. The energy storage bank is meant to power both the light source and USB charging ports for 10 hours daily. However, as part of the customer specifications, the system must be capable of providing light for one day without any sunlight. Our team decided to go a step further and make the system also capable of performing USB charging for one day without any sunlight. As a result, our system requires an energy storage capacity of at least 300Wh. The two major outputs of the system are the light and the USB charging. In order to ensure that each output gets sufficient energy from the battery bank, the team decided to have two separate energy storage banks, one for each output. Therefore, we need a 200Wh battery to power the LED light and a 100Wh battery to power the USB charging. This system ensures that the USB charging cannot take more energy than it has been allocated, and the system is guaranteed 10 hours of light in the night for at least one day with no sunlight.

The batteries we considered had to be sealed, to ensure maximum safety during both transportation and use. Also, the batteries had to be able to operate in ambient temperatures as high as 130°F and have about a 12V output voltage. Taking into consideration that the batteries for these systems could get almost fully discharged, the batteries had to be deep-cycle batteries. This means that the batteries can be discharged to 10.5V or lower without adverse effects on the battery lifespan.

5.4.2 Alternatives

a. Lead Acid Batteries

The two main options for lead acid deep cycled batteries are Absorbed Glass Mat (AGM), and Gel. Within these battery types are many specific brands, which will be discussed later. These batteries are available for purchase in 200Wh capacities and are often used with solar systems.

b. Lithium Ion Batteries

With the lithium ion batteries, brand options include “Turnigy nano-tech,” “Zippy,” and “Rhino”. Factors considered as important for the decision on which battery to go with include price once again, low self-discharge, low required maintenance, safety, and lifetime.

c. Supercapacitors

Super capacitors are capacitors with very high capacitance that provide energy storage. They are most often used as a secondary or tertiary power source in a system where power availability can fluctuate. This is not the situation we are dealing with. Our energy storage needs are for a primary system that does not have frequent fluctuations. Supercapacitors are very durable but also very expensive. The most inexpensive supercapacitor option we found was a 3000F supercapacitor from Maxwell Technologies (Manufacturer part number: BCAP3000 P270 K05). Even using this supercapacitor, the price for the amount of energy storage we require would be about $5000. Because the supercapacitors are so expensive and their intended applications are not relevant to our project, we quickly ruled them out and decided to go with a more traditional battery for our energy storage.

Taking price into consideration, the lithium ion batteries are the most expensive of the three battery options and the gelled lead acid battery is the least costly. To power the system with solely a Li-pol battery, it would cost $250. With an AGM battery, it will cost $90 and $65 with a gel lead acid battery.

An unwanted characteristic of batteries is the tendency to self-discharge. Self-discharging refers to the rate at which a charged battery loses charge if it is left to sit in an ideal situation. Therefore, it is a measure of how well a battery can hold its charge over a period of time. Li-pol batteries generally lose 8% in the first month, while lead acid batteries lose 3% in the first month. At the same time, we desire
batteries that are able to charge quickly. Li-Pol batteries generally charge faster than lead acid batteries (up to 15C), whereas lead acid batteries take comparatively longer to charge.

With regards to safety, the chosen battery should be leak-free and not release hydrogen gas that could cause an explosion. AGM and Lithium ion batteries do not have the problem of releasing hydrogen gas, but when over-charged, gel lead acid batteries release hydrogen gas. Leaking is not an issue with any batteries we looked at, which guarantees no chemical hazards. The final characteristic we looked at was battery lifetime. Lifetime refers to how long the batteries last on average when operated in deep cycling. Gel batteries generally last 2-5 years, AGM batteries 4-8 years, and lithium ion batteries approximately 3-4 years.

5.4.3 Decision

Table 10: Battery Decision Matrix

<table>
<thead>
<tr>
<th>Criteria (score)</th>
<th>Lithium ion</th>
<th>AGM</th>
<th>Gel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price (15)</td>
<td>10</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Low Self Discharge (10)</td>
<td>6</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Fast charging (10)</td>
<td>9</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Safety (30)</td>
<td>25</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>Lifetime (15)</td>
<td>11</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Weight (20)</td>
<td>20</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Total Score (100)</td>
<td>81</td>
<td>86</td>
<td>77</td>
</tr>
</tbody>
</table>

The decision matrix shown in Table 10 indicates the sealed AGM battery as the ideal energy storage option for our proposed system. This type of battery has a long life span as a result of its low self-discharge rate and ability to discharge deeply. Furthermore, this battery is guaranteed to never leak or discharge hydrogen gas.

At first, the team was wary of the idea of using two separate batteries because of the issue of the weight on the pole, but the team decided to consider the option of using lithium ion batteries, which are very light. The big issue was higher costs that came with using lithium ion batteries to completely power the system. The lithium ion batteries required to power the entire system would cost approximately $250 and weigh 6.8 lbs., while the two lead-acid batteries required to power the entire system would cost approximately $90 and weigh 18.6 lbs. Clearly, both the weight difference and the price difference between the two options are substantial. After putting much thought into it, the team decided to come to a compromise between cost and weight. We decided to use lithium ion batteries to power the USB charging and an AGM battery to power the LED light. This brings the total cost of the batteries to $125 and total weight to 14lbs.

Table 11 and Table 12 show the specifications for the selected batteries:

Table 11: AGM Battery Specifications

<table>
<thead>
<tr>
<th>Battery type</th>
<th>AGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Voltage (V)</td>
<td>12</td>
</tr>
<tr>
<td>Min Voltage (V)</td>
<td>10.5</td>
</tr>
</tbody>
</table>
For the AGM battery, we selected the Power Sonic model because we can purchase them at an affordable price for operating temperatures up to 60°C (140°F). For the Lithium ion battery, the Turnigy nano-tech batteries come in packs that maintain the battery temperature at 60°C maximum. Furthermore, of the various options, this model offered the fastest charging and discharging time.

### 5.5 USB Outlets
The system will be able to charge mobile devices through USB outlets. It will have two USB outlets that will be able to charge two mobile phones simultaneously. As stated by the customer, the outlet will be a standard USB 2.0 type A outlet able to provide 0.5A at 5V (typical current and voltage requirements for mobile phones). The outlets will allow charging of mobile devices for a time period that can be specified by the proprietor. The power source for the outlet will be the Lithium Polymer battery array.
5.6 Lighting

5.6.1 Requirements
a. The light sources must consume around 5 Watts of power.
b. Light output must be omni-directional but shall be directed below the horizon.
c. Light source must be able to operate indefinitely in an environment of up to 130 degrees Fahrenheit.

5.6.2 Alternative Technologies

5.6.2.1 Incandescent
The traditional source of lamppost lighting, incandescent light-sources are less energy-efficient than other sources (by producing 95% of their light as infrared), but remain cheap and readily available.

5.6.2.1 Fluorescent
Fluorescent lighting is a more expensive but more energy-efficient alternative to incandescent light bulbs. Fluorescent light bulbs have greater lifetimes than incandescent bulbs but are also more sensitive to temperature change, emitting visibly less light in colder environments. Fluorescent light bulbs also contain mercury, a toxic metal, and thus must be handled and disposed of with care.

5.6.2.1 LED
Light emitting diodes, or LEDs, are more expensive than both incandescent and fluorescent options. However, their useful lifetimes are also significantly greater than both. In addition, LEDs are far more efficient than fluorescent lighting, as well as extremely impact resistant.

5.6.3 Criteria/Decision

5.6.3.1 Type of Lighting
The team created a decision matrix to help analyze the alternatives available for lighting, which is shown in Table 13. Our criteria were based upon the project specifications, constraints, and priorities set forth by the customer (toughness was one variable the customer stressed, but did not constrain). We chose LED lighting as the best light source.

Table 13: Lighting Decision Matrix

<table>
<thead>
<tr>
<th>Decision Matrix</th>
<th>Price</th>
<th>Durability</th>
<th>Power Efficiency</th>
<th>Lifetime</th>
<th>Heat Produced</th>
<th>Environmental Concerns</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Significance</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>6</td>
<td>5</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Incandescent</td>
<td>10</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>151</td>
</tr>
<tr>
<td>Fluorescent</td>
<td>6</td>
<td>3</td>
<td>7</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>180</td>
</tr>
<tr>
<td>LED</td>
<td>1</td>
<td>9</td>
<td>8</td>
<td>10</td>
<td>6</td>
<td>8</td>
<td>273</td>
</tr>
</tbody>
</table>

5.6.3.2 Specific Products
We conducted studies on the light output of conventional lighting systems. Streetlights have an output of anywhere from 10000 to 50000 lumens but also consume 80-500 watts of power. However, this is for industrial areas and beyond the scope of this project. For a smaller area (20 x 20 meters) in a residential neighborhood, lighting recommendations are approximately 600 lumens.
5.6.3.3 Criteria and Alternatives

HCJB only requires that the light source consume around 5 Watts of power. The additional design guidelines chosen by the team are outlined below:

- The light shall consume around 5 Watts of power.
- The brightness of the light shall be at least 330 lumens.
- The light shall operate between 10 and 12V DC.
- The light shall be able to passively dissipate heat.

To fulfill these guidelines, we considered the following alternatives, shown in Table 14.

Table 14: LED Bulb Decision Matrix

<table>
<thead>
<tr>
<th>LED Bulbs</th>
<th>Power Consumption (W)</th>
<th>Voltage (V)</th>
<th>Brightness (Lumens)</th>
<th>Heat sink present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option A</td>
<td>6</td>
<td>12</td>
<td>540</td>
<td>No</td>
</tr>
<tr>
<td>Option B</td>
<td>5</td>
<td>12</td>
<td>450</td>
<td>No</td>
</tr>
<tr>
<td>Option C</td>
<td>8</td>
<td>12</td>
<td>600</td>
<td>Yes</td>
</tr>
</tbody>
</table>

5.6.3.4 Decision

The determinant design characteristic that differentiates the alternatives is their ability to passively dissipate heat. All the options score adequately on fulfilling our design objectives. As a result, Option C was selected to provide lighting for the lamppost.

5.7 Physical Structure

5.7.1 Requirements

a. The lamppost must be built out of 1.5” Schedule 40 galvanized steel pipe. This material is readily available on site in fifteen to twenty-one foot lengths, saving shipping expenses. Table 15 shows specifications for typical steel poles on the market.
Table 15: Steel Pole Specifications

<table>
<thead>
<tr>
<th>Diameter (Inches)</th>
<th>Wall Thickness (in)</th>
<th>Properties of Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>Inside</td>
<td>Outside</td>
</tr>
<tr>
<td>1/8</td>
<td>.269</td>
<td>.405</td>
</tr>
<tr>
<td>1/4</td>
<td>.364</td>
<td>.540</td>
</tr>
<tr>
<td>3/8</td>
<td>.493</td>
<td>.675</td>
</tr>
<tr>
<td>1/2</td>
<td>.622</td>
<td>.840</td>
</tr>
<tr>
<td>3/4</td>
<td>.824</td>
<td>1.050</td>
</tr>
<tr>
<td>1</td>
<td>1.049</td>
<td>1.315</td>
</tr>
<tr>
<td>1 1/4</td>
<td>1.380</td>
<td>1.660</td>
</tr>
<tr>
<td>1 1/2</td>
<td>1.610</td>
<td>1.900</td>
</tr>
</tbody>
</table>

Actual dimensions for 1.5” Schedule 40 pipe are a 1.610” inside diameter, 1.900” outside diameter, and a 0.145” wall thickness, as can be seen from the table above. It is important not to confuse the nominal dimensions with these, as each will provide very different results during strength calculations.

b. The post will be sunk three feet into the ground, and for the purposes of this project may be considered fixed at the point it enters the earth (we will later conduct soil and ground composition analysis in order to determine suitable anchorage and order to double-check assumptions).

d. The light fixture must be a minimum of ten feet above the ground, but not more than eighteen. The maximum length of available piping and the necessary length that to be sunk into the ground will determine the maximum height.

e. There must be a weatherproof, lockable enclosure that is securely attached to the post. The enclosure must contain the two USB-type plug-in outlets and be large enough to accommodate two cell phones while charging.

f. The ambient operating environment will be between 0 and 130 degrees Fahrenheit; all components must be able to operate within these parameters. Higher tolerances may be necessary for components inside closed compartments (the pole, lockbox, or battery compartment).

g. The lamp post structure must be able to survive in constant wind speeds of 40mph and gusts of 60mph (a full analysis will be conducted before the final project report).

h. The lamp post will be in an open area with clear sky above (no trees or buildings will shade the solar panel to any significant effect).

5.7.2 Alternatives
Due to the large number of individual components, we considered many different design alternatives. The physical structure consists of five main pieces: the securable weatherproof charging compartment, the solar panel, the LED, the sealed battery compartment, the foundation, and the pole itself (other minor components are the photo sensor and the cabling. We will consider mounting hardware once the structure design is confirmed). Options we considered are as follows:

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a. Place the battery box at the top of the pole, just above the LEDs, but under the solar panels. The securable compartment would be at an easier access level, about one yard off the ground.
b. Place the battery box at the base of the pole and the securable compartment directly on top of it.
c. Place the battery box at the base of the pole, but place the securable compartment one yard above it, at an easier access point.

All of the designs assume a lighting fixture placed near the top of the pole and the solar panel above that. The reasons for this are twofold. First, this is an assumption made by the customer and industrial consultant. Secondly, placing the solar panel on the ground would create inefficiency in the form of shadows, both from the light post itself (and attached pieces) and from people walking nearby. The solar panel is also somewhat fragile, and implementing it at ground level creates a risk of walking or dropping something on it by accident. This contradicts our design norm of trust, as the proprietor should not have to fear accidental damage to the light post. For the light source, the higher it is placed above the ground, the larger a radius it can light. Placing it above the panel would shield the ground from the light, which would be counter-productive. However, placing the LED under the panel would shield only the sky from the light.

5.7.3 Criteria/Decision
a. The post must be able to carry the load, regardless of where you place the components. The maximum force that may be exerted downward upon the post is 491 lbf (buckling). Therefore it is paramount that upward weight be minimized.
b. Wind places horizontal force upon the pole, which weakens the buckling strength still further. Therefore, it is critical to minimize the wind profile, especially by placing bulky items near the ground.
c. Further calculations will be conducted for each of the alternatives at a later date.
6 Economics

6.1 Business Plan
There are two levels to the business side of our project. One is the production of the system by HCJB, and the other is the micro-business model that HCJB envisions for the use of the lamppost in the place where it is installed.

6.1.1 Production
The team has no say in production methods employed by HCJB but has rather been solely tasked with delivering an optimized design at the end of the project. In this light, the team does not have concrete marketing plans from the customer. However, over the Christmas break, Yoofi Otabil will be travelling to Ghana. The team will attempt to use this opportunity to get concrete information about the market available in this region. This could be done through the use of questionnaires or interviewing of relevant personnel.

6.1.2 Local Micro-Business
The plan for the implementation of this lamppost in third-world countries involves the establishment of a small business around the lamppost. Once HCJB has set up the system, a local proprietor will take over the running of the lamppost. That proprietor will then have the sole responsibility for running, maintaining, and repairing the lamppost system. The proprietor will be able to charge money for people to charge their mobile devices at the lamppost. He or she may charge whatever rate seems appropriate. The duties of the proprietor will include watching over the system to prevent theft, as well as programming the distribution controller for how long the light shall stay on each night.

6.2 Cost Estimates

6.2.1 Operational Cost Estimate
Our team has estimated the following costs for the components of our project, shown in Table 16, which give us a total cost of approximately $800. Since we are receiving $500 from HCJB Global, we are requesting only $300 from Calvin. The most expensive elements are the solar panel and the batteries. We have also included the cost of other electronic elements that we will likely find that we need, although we don’t know what they are right now, as well as additional funds for replacement parts in case we damage some during our testing.
### Table 16: Cost Estimate of Parts

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Panel</td>
<td>$300</td>
</tr>
<tr>
<td>Batteries</td>
<td>$200</td>
</tr>
<tr>
<td>LEDs</td>
<td>$75</td>
</tr>
<tr>
<td>Steel Material</td>
<td>$75</td>
</tr>
<tr>
<td>Microcontroller</td>
<td>$30</td>
</tr>
<tr>
<td>USB cables</td>
<td>$30</td>
</tr>
<tr>
<td>Voltage Converters</td>
<td>$20</td>
</tr>
<tr>
<td>LCD Display</td>
<td>$15</td>
</tr>
<tr>
<td>Other Electronics</td>
<td>$100</td>
</tr>
<tr>
<td>Replacement Parts</td>
<td>$35</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$780</strong></td>
</tr>
</tbody>
</table>

### 6.2.2 Productions Cost Estimate

Our team estimates that it will cost $3,420 per unit to produce our product, as shown in Table 17. Since we do not plan to sell this product for a profit, we did not include a selling price or the cost of marketing and sales.

### Table 17: Production Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Time</td>
<td>$40,000</td>
<td>(400 hours)*($100 per hour)</td>
</tr>
<tr>
<td>Prototype Components</td>
<td>$1000</td>
<td>Taken from Team Budget Request</td>
</tr>
<tr>
<td>Variable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Materials</td>
<td>$1000</td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td>$100</td>
<td>(10 hours)*($10 per hour)</td>
</tr>
<tr>
<td>Distribution</td>
<td>$1000</td>
<td></td>
</tr>
<tr>
<td>Overhead</td>
<td>$500</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$171,000</strong></td>
<td>Per year</td>
</tr>
<tr>
<td>Per Unit</td>
<td><strong>$3,420</strong></td>
<td>Assume 50 produced each year</td>
</tr>
</tbody>
</table>
7 Conclusion
At this point in the project, Team Independent has chosen all of the main components for the prototype. The prototype system will be scaled down from the final design model in terms of the solar panel size and the size of the physical structure. The team has chosen for the prototype a 20W polycrystalline solar panel, a Morningstar SunKeeper charging controller, an AGM battery and an array of Lithium Polymer batteries, an Arduino distribution controller, two switched-mode power supplies, and a 7W LED light bulb as the light source. The team has run simulations to test the strength of the physical system and created a model of the physical structure. Next semester, the team will write the software to implement the tasks of the distribution controller, test all of the system components, and construct a prototype of the system.
8 Sources


http://www.wholesalesolar.com/

http://learn.adafruit.com/photocells/using-a-photocell

http://www.freesunpower.com/batteries.php

http://www.batteriesinaflash.com/deep-cycle-battery-faq

http://www.wholesalesolar.com/products.folder/battery-folder/concorde.html

http://www.bruceschwab.com/pdf/Li-vs-LA.pdf


http://www.instapark.com/solar-power-panels/15w-mono-crystalline-solar-power-panel.html?gclid=CPGrhteuylMCFeXFMgodM1MAjQ


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have supported us all throughout this process.