# A Solar Powered Bus Stop System

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**Abstract**

With the impending exhaustion of the world's energy resources, research and exploration of new alternative energy sources has increased in popularity in recent years. Many have turned to the largest and most ubiquitous form of energy naturally available to fill this energy depletion, solar energy. The practicality of harnessing solar energy as a source of power has shown to be very promising, especially when considering environmental friendliness and economic performance. In response to the demand for the utilization of alternate energy sources, the team proposed a small scale energy conservation project using solar energy technology to remedy the local problem of lighting university bus stops. The group studied different types of solar technologies to find the most efficient and practical type for a bus stop system. After research and design planning, the team determined the right type of solar technology to use: the photovoltaic cell system. The group has taken into account natural complications involved in the decided system and minimized them for optimal functionality. It is the best possible solution for the university's needs.

**Introduction**

Throughout history, people have always seen the sun's power applied to nature. Not only has it been known to heat the earth, but it also gives energy to plants by photosynthesis. Based on this concept, in recent times, people have been trying to harness the power of the sun for realistic purposes. Growing energy concerns have served as impetuses for exploration and experimentation. Solar sails are other examples of solar technology currently in development, which are primarily used in spacecraft propulsion. Likewise, solar panels are used for many applications ranging from large industrial plants to small houses. Similar projects using solar energy have also been planned, such as the Yosemite Transit Shelter [1]. The project plans include creating bus stops using lumber and building-integrated photovoltaic cells. On a more localized basis, solar module technology can be incorporated into the Rutgers project of designing the best possible solar powered bus stop system.

**Background Information**

One organization interested in using such innovative technology is Rutgers University. Rutgers University plans to construct a bus route for its new campus. In an effort to help the environment and potentially save money, the university asked for the six new stops to be powered by solar energy. The task requires enough energy to power four 20-watt light bulbs from 5:00pm to 7:00am every day for each bus stop. This is to ensure the safety of all of their students and bus riders in the late hours of the night. Extensive research according to these demands was required to design these bus stops and ensure that they function correctly.

**Solar thermal collectors**

Solar thermal collectors are usually associated with solar power plants and can be used to generate large amounts of power. They consist of a sunlight-absorbent surface which is usually a metal, such as copper with a black coating. Sunlight strikes this surface, warming it. The heat energy gained is then transported by a fluid through a piping system. This fluid is used to heat water, which produces steam. Like any power plant, this steam works to turn turbines connected to a generator. Solar thermal collectors are generally the most efficient way to convert sunlight to electricity, with efficiencies of up to 30% [2]. Nevertheless, they are impractical on a small scale. Also, because they basically require power plant components such as turbines, generators, piping systems, and the actual collectors, the cost and complexity would far outweigh the advantages. Therefore, thermal collectors could not be used for a bus stop.

**Photoelectric panel**

Photoelectric panels are devices that convert the Sun's energy directly to electricity when electrons are knocked loose and allowed to flow freely. An electric field forces the electrons to travel in a certain direction, creating a current. By placing metal contacts on the top and bottom of the cell, the current can be drawn off and used externally. This type of solar technology would be practical for use at a bus stop because it is already used for roadside emergency telephones in many places. In addition, these panels are very capable of providing sufficient current for up to ten hours of lighting each evening. This is exactly the amount of energy needed for the six

bus stop system. The panels are also a reasonable size for bus stops, and can be easily maintained and serviced. Hence, the solar technology of choice to power all of the bus stops is the photovoltaic cell.

**Important Considerations**

When using photovoltaic (PV) cells, there are many important factors to consider. The first is solar radiation, which is the energy that the sun provides. On average, the density of solar radiation above the Earth's atmosphere is approximately 1367 $W/m^2$, and is known as the solar constant. However, this amount of radiation does not reach the Earth's surface. The Earth's atmosphere absorbs about 19% of the radiation and clouds reflect about 35% of the rays before they reach the surface. As a result, the solar energy received is about 1000 $W/m^2$ at sea level [3]. The amount of solar radiation reaching certain areas on the earth depends, specifically, on the current state of the atmosphere, meaning weather, and the latitude. For example, based on the latitude and weather of Piscataway, NJ, the region receives on average 1150 $W/m^2$. By taking these environmental conditions into account, one can expect to obtain 20 to 50 watts per square meter on a solar cell [4].

Additionally, the rotation of the earth around the sun and the tilt of the planet have a very significant effect. In other words, different seasons produce varying quantities of solar radiation available to the PV cells. Other conditions not caused by nature and closer to the surface, such as pollution, also limit the energy received. Global dimming from pollution hampers solar radiation from reaching Earth. Furthermore, natural surroundings, such as foliage, may have a detrimental effect on PV cells. Shade from these trees and many other sources is one of the most crucial considerations, since it has such a huge consequence on the amount of energy received. Even minor shading can result in a significant loss of energy. For example, if only one of the cells in a 36 cell photovoltaic solar unit is covered, it can reduce efficiency by up to half. Clearly, there are many aspects concerning the sun and earth to consider when planning and designing solar technology

**Experimental/Engineering Design**

The angle and orientation of the solar cells is crucial in the process of acquiring solar energy, since it optimizes the amount of sunlight that can be collected. This is important because if the amount of energy collected is not enough to fuel the system, it will not work. The cells collect the most energy in full sunlight at a general parallel angle to the sun. The direction the panels should face on each of the six bus stops depends on the hemisphere in which it is located. Since this project is based in the Northern hemisphere, the solar panel would have to point due South to the region of the earth closest to the sun, the equator. If a similar project was established in the Southern hemisphere, it would be imperative for the panels to point true North. For this bus stop scenario, a fixed unit, as opposed to a tracking panel, is more practical because tracking units have a larger margin of error and require more maintenance due to their complex nature. The money saved on maintenance will offset the energy loss resulting from improper mounting of the panel. In the case of most fixed solar panels, the angle of the panels is aligned to the most favorable winter conditions. Winter has been chosen because then, conditions are the worst possible. This is because the least amount of sun reaches the earth at this time. By planning for the worst scenario, it guarantees that the system will function under all conditions better than and including it. The angle for most favorable winter conditions is the latitude of the area plus twelve degrees. For Rutgers University, the latitude is roughly 40.5 degrees N [5]. Thus, the optimum angle for this solar panel would be 52.5 degrees from the horizon. Because of the school's request for pleasant landscaping, further considerations must be taken into account. Trees and other obstructions hamper the efficiency of solar cells. Thus, our simple solution was to only have bushes, shrubs, and flowers rather than tall trees. Planning the perfect orientation, location, and angle for the solar panels proved to be quite an engineering feat for the Rutgers solar bus stop system.

Upon evaluating the concept campus in Figure 1.1, there are several disadvantages and advantages to using solar energy at each stop. These problems include location, amount of energy, and type of solar panel. Bus stop A has relatively few problems concerning light availability, as it is in an open place with no buildings or trees to obstruct the direct path of light from the South. The design for this bus stop would be three panels across by two panels deep, as shown in Figure 1.2. Solar panels in the back row would be twice as high as those in the front row to ensure they receive maximum sunlight. In other locations, however, bus stops are

surrounded either by trees, buildings, or a combination of both. It was decided, though, that these trees should be replaced with landscaping shrubs and consequently, would not obstruct the path of the sunlight. Bus stops B and C would not have any problems attaining sunlight as landscaping shrubs would not exceed the height of the bus stop. Over the years, the shrubs would require minor landscaping to ensure that the solar panels are never blocked by their branches. Furthermore, by allowing landscaping shrubs near many of the bus stops instead of entirely omitting all foliage, it would allow Rutgers University to keep its eco-friendly reputation. In the case of bus stop B, the design for the bus stop would be similar to bus stop A in terms of solar panel layout. Although bus stop B is located across a golf course, the golf course poses no immediate threat of damaging the solar panels. In the case of bus stop C, the design for the bus stop would be two solar panels across by three solar panels deep. To solve the problem of buildings obstructing the path, such as in bus stop D, the solar panels may be placed near instead of on top of the stops, in a place free of obstructions. In the case of stop D, where the sunlight is obstructed by the Physics building, an alternate location for the solar panels was imperative. It was decided that the panels should be placed across the street near the gym in order to provide enough sunlight. The solar panel design would be similar to the layout of bus stop A, but located on the ground instead of on top of the bus stop. This is the only case where sunlight is significantly obstructed. When assessing bus stops E and F, both appeared to be in an adequate location to receive sufficient sunlight. Bus stop E was relatively far from the Physics and Health Center building, and thus, would not be vulnerable to its shading. Solar panel layout for bus stop E would also be the same as bus stop A. Bus stop F was similar to bus stop A in that it is also located in an open space with no obstruction to the direct path of light from the South. In the case of bus stop F, solar panel design would be identical to bus stop C. Both bus stops E and F are located near a field that would not be used for recreational purposes. For example, this field would not be used for sports activities, such as soccer or baseball, where a ball might accidentally hit a panel and break it. Although each bus stop is located in a unique area and may have some structural difficulties, utilizing available space and resources has allowed each stop to receive adequate sunlight and function efficiently.

**Choosing a Solar Panel**

To select the proper solar cells for the bus stops, the team then had to assess the power needs based on the anticipated loads of each stop. The plans require four 20-watt light bulbs per stop, each of which will be on from 5:00 PM to 7:00 AM. This translates to a total of 80 watts per stop for 14 hours. Multiplying these figures gives the power requirement of 1120 watt-hours per day (W*h/day) per bus stop. This in turn yields a total of 6720 watt-hours per day for all six of the bus stops in the proposed plan. To account for any technicalities which could increase the load or decrease the power supply, we employed a 25% safety factor, bringing our total power needs per stop to 1400 W*h/day. Using the formula Volts x Amps = Watts, we converted this to Amp-hours per day. When wired to a 15.4 volt battery, this comes to 90.9 Amp-hours per day. The next step was to calculate how much power the sun was able to deliver to the solar cells. In this region of the U.S., the average power of the sun is 4.21 Kilowatt-hours per square meter per day. To account for cloudy days and unexpected shade, we used the daily low value of 3.2 kWh/m2/day. This gave us an amperage value of 28.4 Amps. Based on these calculations, we have chosen solar panels with an operating current of 5.1 Amps. Hence, we will need 6 panels on each bus stop. By using mathematical and electrical formulas, the quantity and strength of the solar cells can successfully be calculated.

The actual solar panel the team will use is an 80-watt solar electric panel manufactured by Silicon Solar Inc. Six panels have a combined area of 43 square feet and weigh 306 pounds. At $350 per panel, each stop will cost $2100, with a campus total of $12,600 [6]. The panels are fairly expensive due to the manufacturing costs of silicon, which is assembled manually and is difficult to purify. But as a result of the increasing demand of silicon production over the last decade, prices have in fact lowered a bit. Furthermore, many jurisdictions now give tax rebates for solar energy, and it is possible that the panels could pay for themselves in a short amount of time.

After successfully setting up the solar arrays, the power generated needs to be used/stored efficiently and safely. There are several options to consider when determining the best method of solar energy usage. In this situation, the solar

Figure 1.1

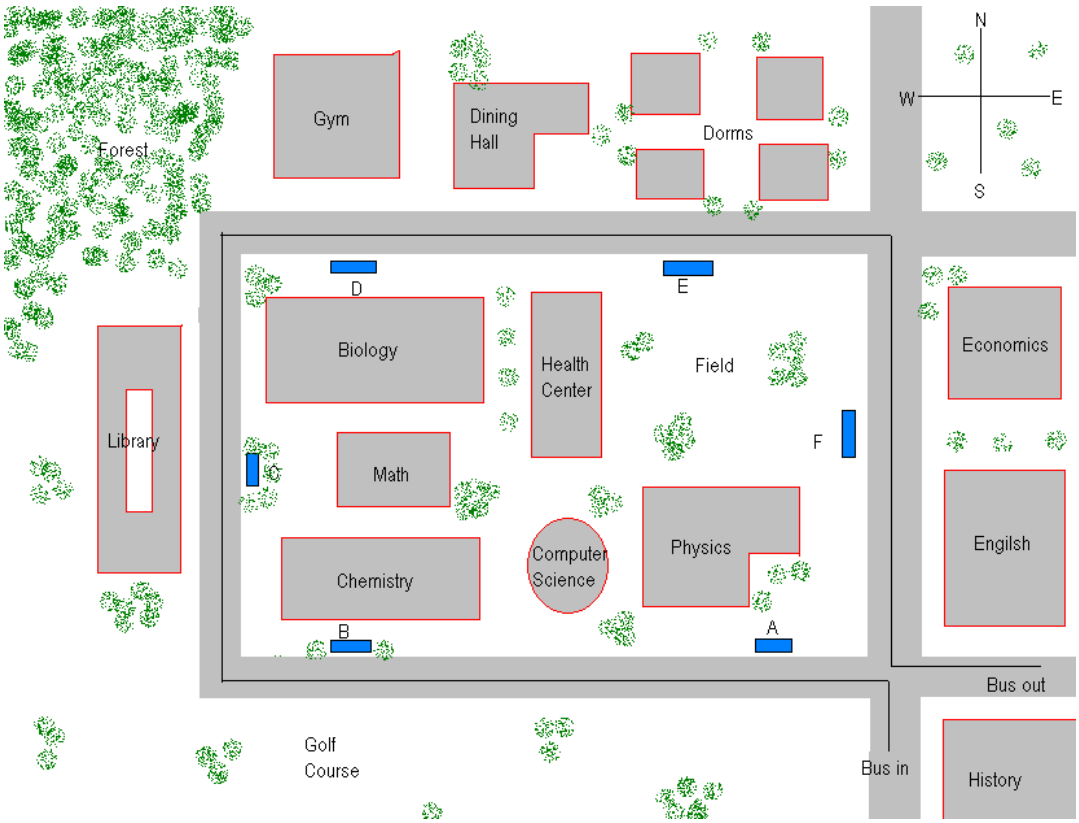
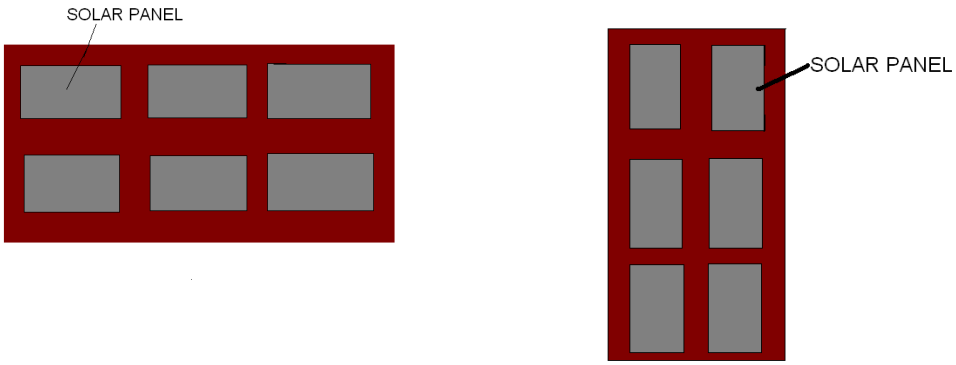



Figure 1.2



array creates a direct current, also known as DC. One option for using this current is to link the system to a utility and use net metering. The solar energy system is linked to a utility company with a two way meter that can measure the amount of energy that is generated by the arrays and the amount that is added by the utility. To use this form of energy storage, an inverter must be purchased to shift the current from DC (direct current) to AC (alternating current) that is large enough to accommodate the size of the current. A significant advantage of tying the solar system to a utility is that energy is always guaranteed, which is advantageous for conditions where enough solar energy can not be generated, such as large durations of rain or snow. Also, although difficult due to enforced regulations, excess energy generated by the panels can be sold to the utility. With this option, however, there are several disadvantages. For one, there are many rules and regulations that must be followed. For example, there must be a safety gauge that allows the current to be stopped at any time, especially when utility workers are maintaining the equipment and property. These complications may result in the need of a lawyer, which may be too extreme for the Rutgers bus stop purposes. Thus, this choice may be impractical for the small scale project of Rutgers University.

Another alternative for storing and using the energy is to simply use batteries. The DC current can be stored in batteries of a reasonable size, about the size of a car battery. The batteries can be charged and discharged throughout the course of the day, with the collection of and use of solar energy. An advantage of using batteries is that it is a compact, less costly method of energy storage, compared to net metering. It is also important to consider that batteries need to be changed periodically. Additionally, the batteries must be kept in water, the temperature and level of which needs to be monitored. Furthermore, the batteries must be ventilated at all times because the batteries release hydrogen, an explosive gas. But by keeping the batteries in a ventilated structure at the side of the bus stop, majority of these issues can be addressed successfully. Upon close comparison of net metering systems and battery storage, the team has decided to use batteries for energy storage. By analyzing the pro's and con's of both options, batteries prove themselves the best method of storing the energy produced by the solar arrays.

Now that all the full details are known, our final decisions should be reiterated. We began by analyzing the locations of the bus stops. We discovered that majority of the locations were in relatively open areas, which would facilitate our decision to place solar panels on top of the bus stops. The solar arrays will be mounted in a tiered format in order to ensure that no array is shaded. Several bushes and shrubs around the stop can be included although they must not exceed the height of the bus station. But one position, bus stop D, was fully obstructed by a building. Our options were to place the solar panels on the building or to place the panels in another location and wire them to the lights in the bus stop. Placing panels on top of buildings, however, would not allow for Rutgers to display its innovative new technology. Thus, we determined that the best course of action to fix this hindrance would be to place the solar panels across the street near the gym and wire the current under the road to the bus stop. Since most of the other bus stops are able to receive light without any obstructions, the solar panels that will power them could be placed right on top of the bus stops.

Once the position of each solar panel was decided, we had to determine what type of solar panel to use. There were many other factors that appeared with this issue. Not only did the team have to establish which type of solar panel, but also the size, the number of panels, and the peak current. The manner of storage also needed to be decided, whether to use a battery or capacitor to store excess energy, or to wire the solar panels to the nearest grid so that the energy can be collected there. In addition, since solar panels are expensive pieces of technology, cost played a major role in the final decisions. After performing extensive research and numerous calculations, we finally settled on one specific type of solar panel, the photovoltaic cell.
Since each bus stop would use four twenty-watt light bulbs, each stop would require 80 watts of power from the solar panels. Specifically in the Piscataway, New Jersey region, the group found that the sun provides 1150 watts per square meter of energy that can be utilized by the solar panels. Calculations were done to show that by using a 15.4 volt battery and solar panels with peak currents of 5.1 amps, we would need 6 solar panels for each bus stop. After determining the amount of energy the solar panels would provide, the group decided to store the energy in batteries to retain some of the excess energy

collected during the daytime. This would allow the bus stop to be powered during the nighttime when there is no sun, as well as on cloudy days when sunlight cannot reach the sensitive photovoltaic cells.

**Results**

Based on the research the team conducted, it is apparent that there are several advantages and disadvantages to using solar technology. The team learned that there are many aspects of building new technologies that need to be accounted for such as the earth's positioning, landscaping, and weather. Despite these complications, it is still possible to build a fully capable design. In this design, each of the six bus stops uses six solar panels to generate enough energy to power light bulbs through the night. The dimensions of the proposed design can be scaled to represent an actual bus stop-- seven feet six inches high, nineteen feet seven inches long, and nine feet eight inches wide. However, although calculations may seem accurate and may represent real life, the actual design of the bus stop has yet to be tested on a computer simulation. The team realizes the limitations of its design and understands that no conclusive data can be determined by simply using mathematical formulas and research.

**Future Work**

With the information gathered from the research, the team came up with several suggestions to make solar energy more effective in a future campus. One suggestion is to avoid placing the bus stops where their southern orientation is obstructed by a building. As explained earlier, solar arrays need to be in the direction of true South. A future consideration of this would ease the process of building solar-powered bus stops, possibly would lower the cost of constructing panels in different locations and wiring to route the energy. Shading, as previously discussed, is an important issue for solar power and can cause severe problems in energy production. This does not mean that bus stop must be placed far from the buildings, for this will be inconvenient for students and faculty. Rather, the arrays should be placed in positions that receive the most solar radiation. Also, the number of trees or shrubs next to the bus stops should be reduced. More specifically, the heights of these bushes will also need to be controlled since branches cannot block the solar rays without interfering with the solar radiation absorption. These key factors should greatly be accounted for in future work to construct a solar bus stop system.

Other changes include reducing the number of light bulbs placed in each bus stop. Instead of having four individual light bulbs using energy and wiring all of them, the university should put one bigger light bulb at the center of the bus stop. It is unnecessary to wire four separate light bulbs in each of six bus stops, especially when considering the risks of short circuiting and other potential problems.

Moreover, the team questioned whether it was beneficial or not to have the solar panels placed with the bus stops. Some bus stops were inconveniently placed in positions where they were covered by buildings. The team suggested relocating the solar panels father away from the bus stop and using an underground cable to transfer the energy to the bus stop. Another possibility is that the bus stops could be unified into one single solar unit large enough to power every bus stop in the system. Clearly, this offers several advantages—maintenance would be easier and an optimal location could be used to provide energy for all the bus stops, eliminating the need for awkward wiring and other complications.

Likewise, the addition of a computer system with sensors to change the angle of solar panels would bring about greater efficiency by directing the panels to move according to the angle of peak solar radiation according to the time of day and the season of the year. Although this suggestion seems to be the perfect solution, it is important to acknowledge the need for a qualified person to monitor the computer tracking systems. This device could pose inconvenient and costly.

Another future project could be the introduction of an emergency telephone alongside each of the six the solar powered bus stops. They would allow further safety for the waiting passengers and would provide a network of telephones around the area that can be used at anytime since they are powered by the same energy of the photovoltaic cells on the bus stops. But on a much larger scale, solar powered busses could be introduced to complete the solar powered bus route. They would be a great deal more economical and environmentally friendly than the commonplace busses of today that run on gas and release tons of pollutants into the air. Nevertheless, certain suggestions can bring about

useful advantages and are essential to consider in making decisions.

**Conclusion**

The Rutgers University bus stop system has been analyzed and studied deeply. The many factors of building solar technology have been considered, and for this project, the use of photovoltaic cells in solar arrays seems ideal. The significance of understanding the technology and environmental issues have clearly been recognized, and as prospective engineers, the team has realized the great extent to which matters must be evaluated before launching modern and innovative technology.

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**Citations**

1. Eiffert, Patrina Ph. D and Gregory Kiss. "Building Integrated Photovoltaic Design for Commercial and Instutional Structures". February 2000. http://www.imaginit.cc/bipv.pdf

2. "Solar Energy". 10 July 2006. http://en.wikipedia.org/wiki/Solar_energy.

3. Ibid.

4. Solar, Akeena. "What Size Solar Electric Energy System Do I Need?". 10 July 2006. http://www.akeena.net/size/index.html

5. "Piscataway Community Profile". 10 July 2006. http://eopdunk.com/cgi-bin/genInfo.php?locIndex=18424

6. "Silicon Solar Inc". 10 July 2006. http://www.silicon solar.com/shop/catalog/20-Watt-Solar-Electric-Panel-p-16208.html