Comparison of Energy Efficiency, Eco-Friendliness, and Cost and Convenience of Phase-Change and Biosolar Materials in Solar Panels

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Honors Research Practices

Abstract

Solar energy is a clean, renewable energy source that is a good alternative to nonrenewable energy sources. Currently, the two major materials utilized in solar panels are phase change materials (PCMs) and biosolar materials. The purpose of this study is to determine whether biosolar materials or phase change materials are better overall, in terms of energy efficiency, cost and convenience, and eco-friendliness in solar panels. Utilizing solar panels that implement phase-change materials or bio-solar materials, this study explores the energy efficiency, cost and convenience, and eco-friendliness, in a variety of different conditions and designs, for each type of material. To ensure that an overall finding on the better type of material can be found, this study uses a rating system, based on government regulations, industry standards, experimental data, and common scientific values. It is expected that there is higher energy efficiency with the utilization of phase-change materials than with bio-solar materials. However, it is expected that the bio-solar materials are more eco-friendly than the phase-change materials. Overall, it is expected that bio-solar materials are the better choice for solar panels because of their eco-friendliness, low cost, and similar energy efficiency to phase-change materials. The findings of this study can help to push communities to make an informed decision on a switch to renewable energy methods. More importantly, this study supports the use of clean, renewable energy with biosolar material solar panels, to combat rapid change in global climate and negative impacts of most nonrenewable energy sources.

I. Introduction

Current energy production methods are not sustainable and are doing harm to the environment. Luckily, alternative methods, such as wind and solar energy, can provide necessary amounts of energy to power communities, eliminate much of the use of nonrenewable resources, and minimize harm to the environment. However, many renewable energy methods are not as efficient as current, nonrenewable methods, making it difficult to convince consumers to make the switch. Additionally, most of the solutions have a high upfront cost without an immediate return on investment. This can make renewable alternatives challenging to implement without the right resources, such as money, time, and space. Despite the issues facing renewable energy, the need for it is dire. Current nonrenewable methods produce greenhouse gases as a byproduct, which can cause serious harm to the atmosphere if not monitored and kept under control (Akhtar, Hashmi, Ahmad, & Raza, 2018). As electricity becomes of greater necessity to communities, more of it needs to be produced, leading to the release of more greenhouse gases and a rise in global climate. If the formation of additional greenhouse gases is not reduced or stopped, the increasing global climate can have damaging consequences on many ecosystems and communities around the world. Therefore, renewable energy is a promising alternative to current nonrenewable energy, as long as the renewable methods can continually provide the energy necessary to keep communities running.

One of the most promising renewable energy methods is the use of solar panels. Currently, most solar panels are comprised of photovoltaic (PV) cells that are made with silicon junctions. Despite being the most commonly used material in solar panels, silicon PV cells have many drawbacks. First, silicon PV cells are generally not biodegradable. Once PV cells reach the end of their usable life, they cannot be disposed of properly and can become harmful to the environment (CRC Press, 2018). Given that one of the main reasons for using solar panels is to maintain eco-friendliness, the fact that solar panels with PV cells do more harm at the end of their lives is not ideal. Second, the cost of installing and maintaining larger applications of silicon PV solar panels, such as solar farms, to provide necessary amounts of energy can be a roadblock for many communities (Chan, Evans, Grimley, Ihde, & Mazumder, 2017). Additionally, because large solar farms are often in areas where there is a lot of wind and dust, keeping the panels clean can become a problem. Solar panels need to be clean for optimal energy efficiency, but ensuring that dust does not accumulate on the panels requires a certain amount of labor and diligence. Current solar panel materials and methods work well, but there are many improvements that need to be made in order for solar energy to be a highly appealing renewable energy source.

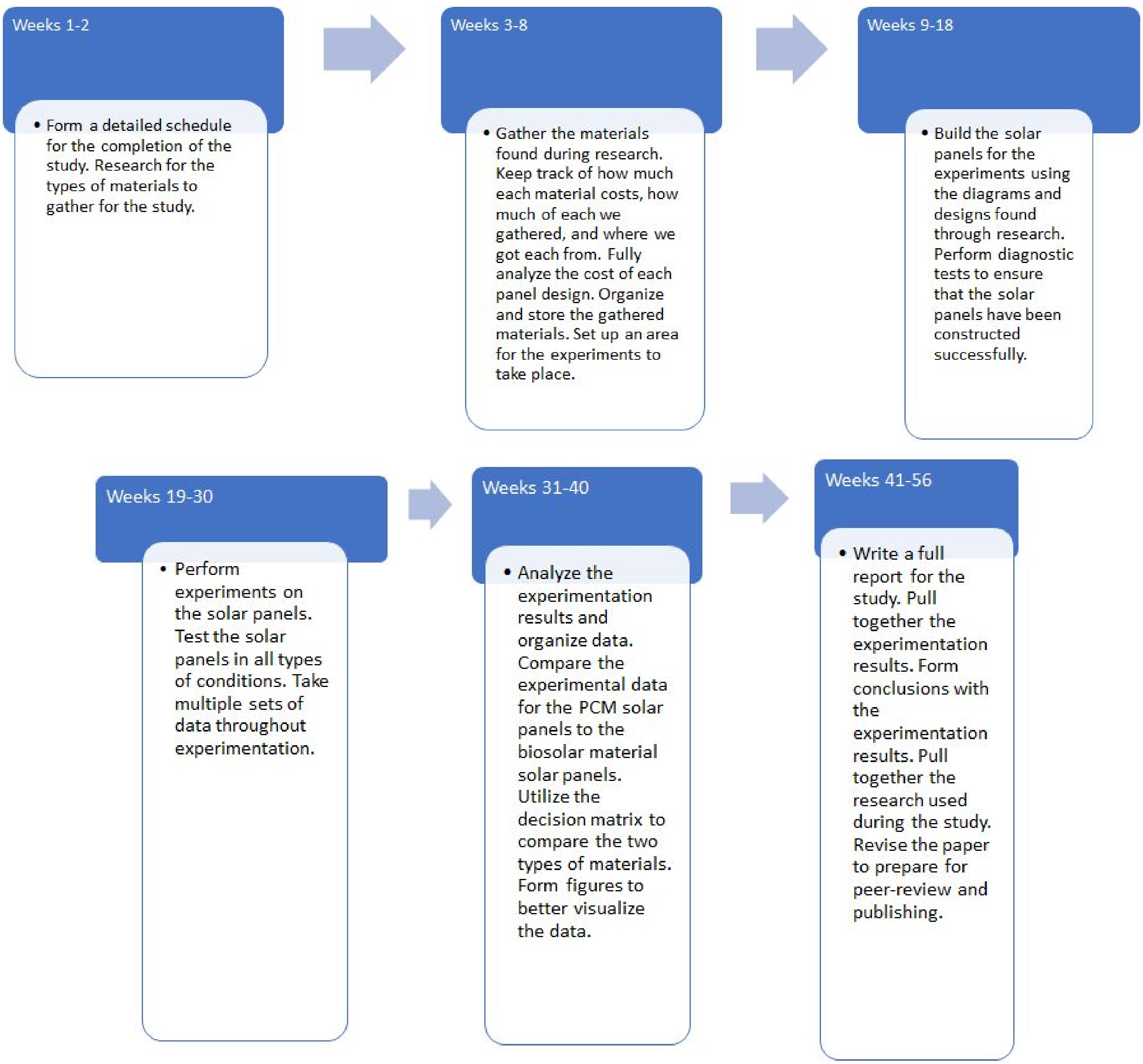
Two of the most popular materials currently being researched for solar panels are phase change materials and biosolar materials. Phase change materials (PCMs) are currently a common method for storing extra energy to use when the solar panel is not producing electricity. In much the same way as water changes phase when it is heated or cooled, PCMs store energy by changing crystalline structure to absorb energy (Dwivedi, Tiwari, & Tiwari, 2016). Different types of PCMs have different melting points which affect their efficiency in certain environments and usage levels (Su, Jia, Lin, & Fang, 2017).PCMs are very useful in solar panels since they can hold their shape, have “high thermal conductivity,” and are resistant to corrosion (Dwivedi et al., 2016). However, these materials are also very expensive and need to be connected to a panel that generates electrical energy since they cannot directly generate electricity from sunlight (Dwivedi et al., 2016). Biosolar materials are a possible alternative to PCMs. Biosolar materials generate electricity by harnessing the electrons released during the photosynthesis and respiration cycles inside microorganisms (Reshma, Chaitanyakumar, Aditya, Ramaraj, & Santhakumar, 2017). An advantage of using biosolar materials is that they do not need to be used in conjunction with different materials for generating electricity and can form the whole solar cell. However, this method requires specific species of bacteria and has drawbacks of being a self-contained system (Reshma et al., 2017). Preliminary testing has shown that biosolar cells work best in smaller panels (Wei, Lee, & Choi, 2016). Therefore, more efficient systems must likely be many small cells connected together, making production, installation, and maintenance more labor-intensive and complicated. In order for communities around the world to make the switch to solar panels for renewable energy, the production of efficient, cost-effective, convenient, and eco-friendly solar panels is of utmost importance. Our research intends to compare PCMs and biosolar materials, in terms of efficiency, cost and convenience, and eco-friendliness, to make a definitive statement on the better type of material to use in solar panels. Based on the research that we have conducted, we hypothesize that biosolar materials are most likely the better option to use in solar panels, as long as the development of solar panels using such materials continues at the current pace.

II. Methods

Timeline and Completion of Study

The study will span approximately 56 weeks. This gives our group enough time to organize the experiments, gather and analyze data, and write a full paper using the results.

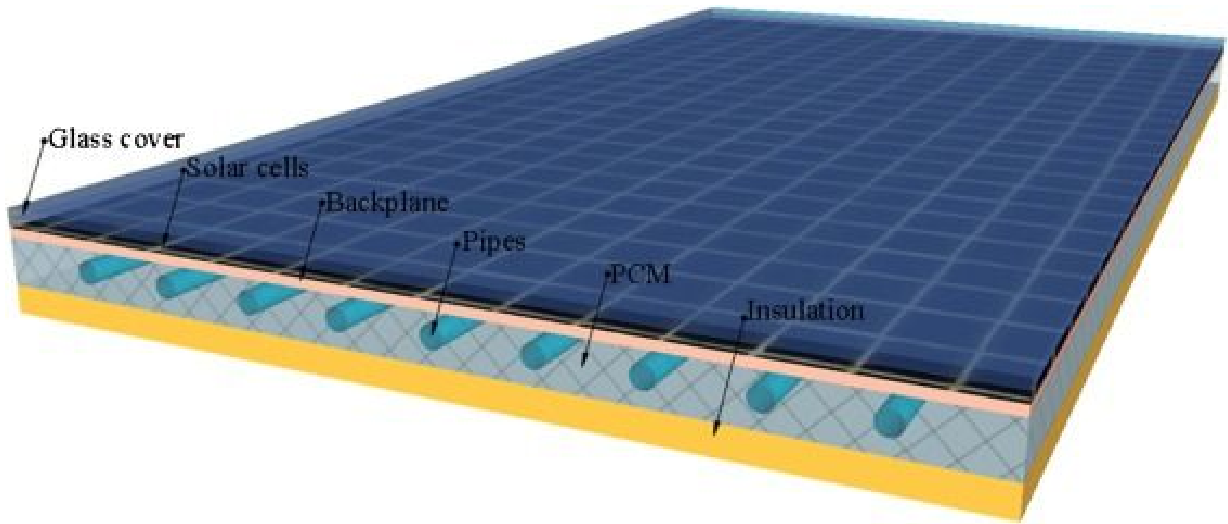
Figure 1. Timeline and General Milestones for Study



Design of Phase Change Material Solar Panel

Our group plans to design the PCM solar panels according to the layout used by Su et al. (2017), as depicted in figure 2.

Figure 2. Basic Layout of PCM Solar Panel (Su et al., 2017)

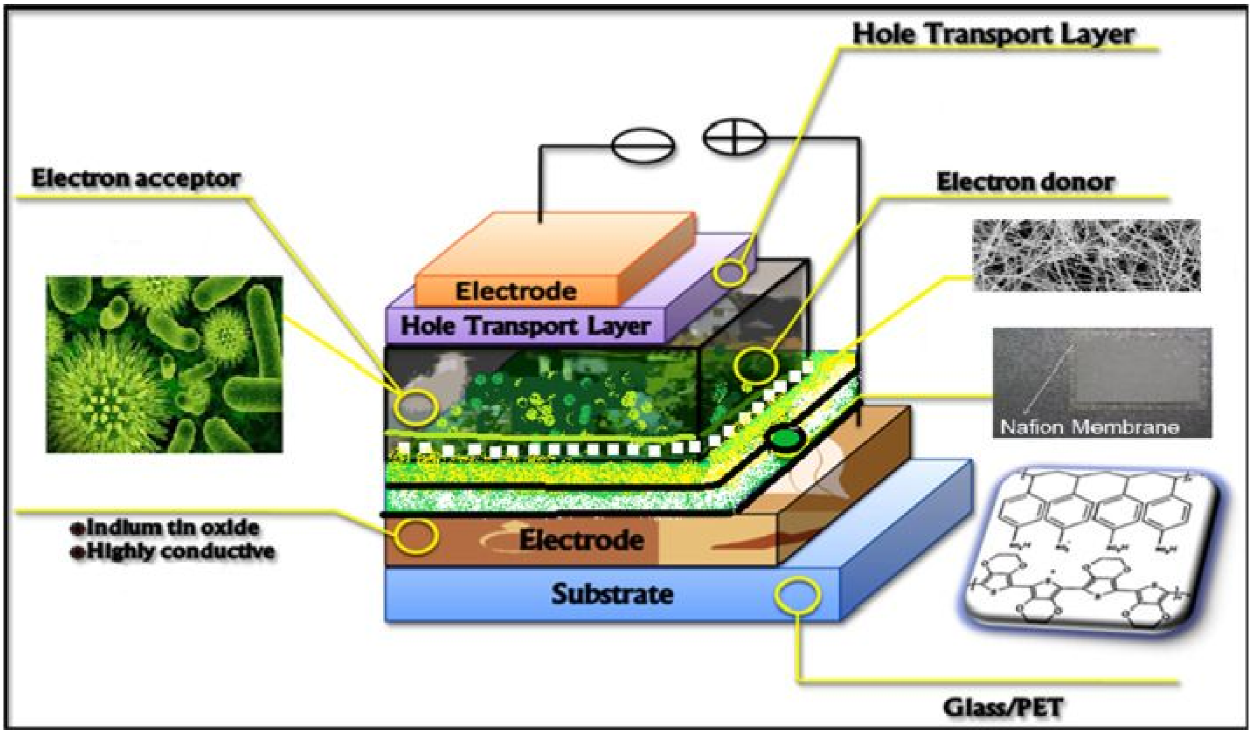


We will use PCM with a melting point of 30 °C, which was determined to have the best electrical efficiency by Su et al. (2017). As shown, the solar panel will be made with a glass covering, under which the solar cells will be placed. The PCM will be placed throughout the solar panel, underneath the solar cells. Consequently, the PCM will have room to undergo phase changes. Pipes will be placed in the PCM for energy to be easily transferred from the solar cells and PCM to circuits.

Design of Biosolar Material Solar Panel

Our group plans to design the biosolar material solar panels according to the layout used by Reshma et al. (2017), as depicted in figure 3.

Figure 3. Basic Layout of Biosolar Material Solar Panel (Reshma et al., 2017)



We will use the cyanobacterial strain *Synechocystis* sp. PCC6803, which was determined to have the best power output by Reshma et al. (2017). The solar panel will have a glass covering made of polyethylene terephthalate (PET), because of the PET's good transparency. The cyanobacteria will be placed above an electrode and under a transport layer. This allows for the energy from the cyanobacteria to be easily transferred through the solar cell and to circuits. Highly conductive electrodes will be used to support the transfer of energy from the cyanobacteria.

Efficiency

Throughout the study, we will use voltmeters, ammeters, and small circuits to measure the voltage and current produced by the solar panels. Voltmeters and ammeters are instruments that can measure voltage and current, allowing for us to calculate the power output of each solar panel. In order to use the voltmeters and ammeters, we must connect small circuits to the solar panels. Small circuits will allow us to attach the voltmeters and ammeters to measure the voltage and current produced by the solar panels. After gathering voltage and current data for each type of solar panel, we can use the relationship between voltage, current, and power to calculate the power output and efficiency of each type of solar panel. This relationship is a directly proportional relationship and can be easily calculated.

Throughout the study, we will measure the power output of the solar panels in the morning, afternoon, and evening. Furthermore, the solar panels will be subjected to different conditions, with test variables including amount of sunlight exposure, cleanliness of glass covering, temperature, weather, and more. This will allow us to have a good range of data to ensure accuracy when calculating the overall power output of the solar panels. The determination of an efficiency rating for each type of material will be quantitative and based upon current power outputs of solar panels.

Eco-friendliness

Throughout the study we will attempt to measure the effects of each type of solar panel on the environment. During experimentation, we will measure the effects created by each material on natural water and air. Additionally, after experimentation on the solar panels and disposing of the solar panels, we will measure the effects of each type of material on the environment in which they are disposed of. We will compare the data that we collect to current environmental regulations and industry standards. From the comparison of the data, we will rate the eco-friendliness of each type of material.

Cost and Convenience

Throughout the study, we will keep track of the materials that we use, how much we use of each material, and how much each material costs to calculate the overall costs for both types of solar panels. We will create and update a spreadsheet as we make each solar panel or solar cell, listing all of the components used and their respective costs. As the experiment is in progress, we will take note of any worn materials that may denote a need for replacement. Additionally, we will look for alternative materials to potentially test to see if there is a benefit to using more or less expensive materials to build the solar panels. Maintaining proper data on the costs to build the solar panels will help us in rating the cost associated with each type of material.

In comparing convenience, we will look at ease of installation, maintenance, and versatility. Ideally, a material would be easy to install on any standard home for individual consumer use, or in large-scale operations for community use. Required maintenance is important because a solar panel that requires less frequent maintenance to work at optimal efficiency requires a less amount of time for someone to spend working on it over the course of its lifetime. We include versatility as a factor of convenience because there will likely be different climates for a solar panel to face. It is important that the solar panel can withstand various environments, including, but not limited to, heavy rain, extended periods of direct sunlight, bitter cold, extreme heat, and extreme winds. The data on convenience will likely be mostly qualitative.

Decision Matrix for the Comparison of Materials

Table 1. Decision Matrix in Comparing Aspects of PCMs and Biosolar Materials

Category	Phase Change Materials (PCM)	Biosolar Materials
Efficiency		
Eco-Friendliness		
Cost		
Convenience		

* Poor +, Average ++, Good +++, Excellent ++++

Table 1 shows the layout for the decision matrix that we will use to formulate a conclusion on the better type of material. The data that we will gather will be used to rate each type of material in each aspect of our comparison. Each type of material will be rated as poor, average, good, or excellent in each aspect of our comparison. Each aspect of our comparison will have equal weight when forming our final conclusion.

III. Expected Outcomes

Table 2. Decision Matrix in Comparing Aspects of PCMs and Biosolar Materials

Category	Phase Change Materials (PCM)	Biosolar Materials
Efficiency	++++	+++
Eco-Friendliness	++	++++
Cost	++	+++
Convenience	+++	++

* Poor +, Average ++, Good +++, Excellent ++++

Table 2 shows our expected ratings for each type of material using the decision matrix. First, we expect that the efficiency of the PCM solar panels will be much higher than the efficiency of the biosolar material solar panels. Our assumption is supported by the efficiency findings for PCMs by Dwivedi et. al (2016) and Fallahi, Guldentops, Tao, Granados-Focil, & Van Dessel (2017), and for biosolar materials by Reshma et al. (2017). However, because biosolar material solar panels are still in the beginning stages of development, we believe that the efficiency of biosolar materials will be able to come close to the efficiency of PCMs with more research. Second, we expect that biosolar materials will be much more eco-friendly than PCMs.

PCMs appear to be much harder to dispose of than biosolar materials. Furthermore, the chemical components of PCMs can have negative effects on the environment if not properly contained. Biosolar material solar panels utilize cyanobacteria until they die and will have no harsh effects on the environment, making biosolar materials a much more environmentally friendly option. There is currently no definitive research on the environmental effects of both types of materials. Third, we expect that the costs of the two types of material will be relatively close to each other. However, it is most likely that biosolar materials will be less costly than PCMs, as the cyanobacteria in biosolar material solar panels can be grown and are self-sustaining (Reshma et al., 2017). PCMs are made out of expensive chemical compounds, thus solar panels that utilize them can quickly become expensive, as supported by Fallahi et al. (2017). Lastly, we believe that PCMs will be much more convenient than biosolar materials. PCMs can last for long periods of time in solar panels and require less frequent installations. In contrast, biosolar materials are self-sustaining, but solar panels that utilize them will need more frequent installations of cyanobacteria due to the cyanobacteria's short lifetime. The level of extra maintenance, other than installations, of the two types of solar panels is most likely the same.

IV. Interpretation of Outcomes

Our expected ratings for the efficiency and convenience of biosolar materials are lower than those of the PCMs, however we expect that the data for these categories will be relatively similar. Consequently, our decision will most likely come down to the eco-friendliness and cost of the materials. Therefore, from our expected results, we believe that biosolar materials will be the better choice when looking at efficiency, cost and convenience, and eco-friendliness.

From our expected outcomes, we believe that biosolar material solar panels will be the best choice of solar panel material for communities to use as renewable energy. Biosolar material solar panels will be efficient, eco-friendly, and low cost energy providers. The finding that biosolar materials are the best type of material to use in solar panels can help current solar panel developers and researchers in the design, experimentation, and production of solar panels. Furthermore, solar panels that utilize biosolar materials could eliminate hesitations by communities to make the switch to renewable energy. Consequently, biosolar material solar panels could begin a global movement to "greener" energy choices and less of a carbon footprint left by society.

Suggestions for Future Work

From our study, we suggest that future work should focus on the development of biosolar material solar panels. We believe that the efficiency of biosolar material solar panels can be greatly improved if further research is conducted. Additionally, further development of biosolar material solar panels could lessen negative environmental effects and lower costs of solar panels. Most importantly, further development of biosolar material solar panels could push communities around the globe closer to a major switch from nonrenewable energy methods to renewable ones.

Consequently, with further developments, biosolar material solar panels could decrease greenhouse gas concentration and halt global warming.

V. Pitfalls and Ethical Concerns

One pitfall that our group may face is problems in building the solar panels. Human error or issues with the materials may cause some of our solar panels to not function properly. In order to address the possibility of this issue, extra materials will gathered and stored as backup. Another pitfall that our group may face is problems with the designs of the solar panels. The designs that we plan on using for our solar panels may not work with the materials and methods that we plan on using. If this issue arises, we will make slight design adjustments for the solar panels to function properly. A third pitfall that our group may face is completing the study within the estimated time. In order to meet the estimated completion time for our study, schedules, plans, and assignments for each day, week, and month will be set and distributed to each group member. Moreover, communication through group messaging systems and online collaboration applications will be used.

Most of the ethical concerns pertaining to our research are environmental concerns. Many of the materials in our experiments can cause harm to the environment if not properly maintained or disposed of. For example, the bacteria in the biosolar cells should not be released into random environments because they can become invasive to the ecosystems. Additionally, the PCMs should not be released into environments because their chemical components can contaminate ecosystems. Since we will be testing the solar panels outside, we will ensure that they are in an area where their materials will not be tampered with or released to the environment. Throughout the project, environmental regulations and standards will be met and reviewed regularly. Other unforeseen ethical concerns that may arise during our study will be addressed in an effective and timely manner.

VI. References

Akhtar, S., Hashmi, M. K., Ahmad, I., & Raza, R. (2018). Advances and significance of solar reflectors in solar energy technology in Pakistan. *Energy & Environment*, *29*(4), 435–455. https://doi.org/10.1177/0958305X18758487

CRC Press. (2018). *Handbook of Chemistry and Physics 99th Edition*. Retrieved from http://hbcponline.com.ezproxy.lib.vt.edu/faces/contents/ContentsSearch.xhtml;jsessionid=68647C0B348AF026AEB8

Dwivedi, V. K., Tiwari, P., & Tiwari, S. (2016). Importance of phase change material (PCM) in solar thermal applications: A review. In *2016 International Conference on Emerging Trends in Electrical Electronics Sustainable Energy Systems (ICETEESES)* (pp. 42–45). https://doi.org/10.1109/ICETEESES.2016.7581349

Fallahi, A., Guldentops, G., Tao, M., Granados-Focil, S., & Van Dessel, S. (2017). Review on solid-solid phase change materials for thermal energy storage: Molecular structure and thermal properties. *Applied Thermal Engineering*, *127*, 1427–1441. https://doi.org/10.1016/j.applthermaleng.2017.08.161

Reshma, L., Chaitanyakumar, A., Aditya, A. L. G. N., Ramaraj, B., & Santhakumar, K. (2017). Modeling of microfluidic bio-solar cell using microalgae through multiphysics platform: A greener approach en route for energy production. *Algal Research*, *26*, 47–55. https://doi.org/10.1016/j.algal.2017.07.002

Su, D., Jia, Y., Lin, Y., & Fang, G. (2017). Maximizing the energy output of a photovoltaic–thermal solar collector incorporating phase change materials. *Energy & Buildings*, *153*, 382–391. https://doi.org/10.1016/j.enbuild.2017.08.027

Wei, X., Lee, H., & Choi, S. (2016). Biopower generation in a microfluidic bio-solar panel. *Sensors and Actuators B: Chemical*, *228*, 151–155. https://doi.org/10.1016/j.snb.2015.12.103