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Living Energy: A Novel Approach to Using Biofluorescent Bacteria in Solar Concentrators

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Abstract

To combat pollution, habitat degradation, and waste of limited resources, scientists and environmental activists advocate for renewable energy – cleaner, inexhaustible forms of power. While there are numerous positives to this energy type, it is more expensive, more intermittent, and less efficient than readily available fossil fuels. For example, solar panels are only 15-21% efficient on average. One solution, the solar concentrator, uses reflective properties of glass to concentrate light towards a solar cell. This project investigates the integration of biofluorescent bacteria into concentrator photovoltaics, using visible light produced by these bacteria as an additional source of photons for solar cells. The purpose was to test how much this biofluorescent bacteria-based solar concentrator can enhance the power output of photovoltaic cells. The experiment consisted of 10 trials containing control glass concentrators and concentrators with biofluorescent *E. coli*, for a total of 1.5 hours under simulated light conditions and 1.5 hours in the dark. The power (wattage) of each recording was calculated at 15-minute test intervals and used to compare the control and bacteria-applied solar cells. On average, application of biofluorescent bacteria resulted in a power output increase of 61.46% in the light simulation and 273.6% in the dark. These findings suggest that the enhancement of photovoltaic cell performance using biofluorescent bacteria on a solar concentrator can allow for greater amounts of energy to be output by real-world solar panels.

Author's Note

One fall morning, I sat quietly in my eighth-grade homeroom, studying photosynthesis – the light and dark reactions of plants – for my upcoming biology test. I was fascinated by how plants generated energy from the Sun during the day and continued to use that energy even after the Sun bid us adieu. After reading through a few chapters of my biology textbook, I began to doodle, and my mind wandered. If plants can provide energy for themselves around the clock, why can't solar panels provide constant energy for us? What started as a typical morning turned into the beginning of something spectacular, and after five years of intensive research and countless hours of testing, my partner Andrew and I created the biofluorescent solar concentrator. This design, a (quite peculiar!) mix of

biofluorescent bacteria, glass, and solar panels, surmounts a major hurdle of widespread solar panel use – their limited response ranges.

Keywords

Solar panels, PV cells, photovoltaics, biofluorescent bacteria, renewable energy, clean energy

Introduction

Currently, the Earth is predicted to sustain life for another 1.75 billion years (University of East Anglia, 2013), assuming unnatural factors do not cause its premature demise. Unfortunately, the rapid depletion of natural resources, such as water, vegetation, and fossil fuels, is disconcerting to scientists even today. Additionally, greenhouse gases from fossil fuel use and the potential for global climate change may make Earth uninhabitable to humans sooner than anticipated (May, 2014).

Scientists are investigating ways of transitioning to renewable energy to help prolong the planet's sustainability, recognizing that such a transition would decrease the emission of harmful gases, in turn lowering the rate of global climate change (Union of Concerned Scientists, 2017). Because they produce "significantly less carbon emissions compared to fossil fuels" (Sources of Energy: A Comparison), renewable resources are cleaner. Unfortunately, this energy type is complicated by high costs, unreliable hardware, and low efficiency rates.

All renewable resources can produce more than 15 terawatts (TW) of energy and have high theoretical potentials. However, only solar and wind energy have extractable potentials, potentials that can convert to an easily transportable chemical form (Tsao, Lewis, & Crabtree, 2006). Solar power is one of the more common renewable resources, and its popularity has increased since its conception. In 2018, solar energy generated 2.2% of the United States' electricity, compared to only 0.7% in 2014 (Lawson, Sherlock, Platzer, Clark, & Cowan, 2020). Unfortunately, solar energy heavily depends on the availability of sunlight and is only 15 to 21 percent efficient (Johnson, 2013), a problem researchers hope to solve through technological development. While solar batteries that store generated energy for later use seem like a tempting solution, they are expensive, costing users $11,000 - $18,000 (How much does solar storage cost? Understanding solar battery prices, 2020).

The amount of sunlight energy striking the Earth in less than two hours (89,300 TW) is greater than "the worldwide energy consumption in the year 2001 from all sources combined" (Tsao, Lewis, & Crabtree, 2006). A more affordable, efficient method of harnessing this energy would fulfill the world's energy needs and requires a thorough assessment of the solar panel's weaknesses. One such weakness is investigated in this study. Because standard solar panels cannot absorb ultraviolet (UV) rays from the Sun and instead rely solely on longer wavelengths of visible light, their productivity declines on overcast days and in low-light conditions (Steffen, 2020). Tackling this hurdle may increase solar panel efficiency.

Background

I. Solar Cells

Solar energy is converted into usable energy though flat arrays of photovoltaic (PV) cells. These cells work using the photoelectric effect, in which "photons are absorbed and electrons are released and are captured as electrical energy" (Photoelectric effect, Encyclopedia Britannica, 1998). In a PV cell, light strikes a thin wafer of semiconductor material, such as silicon, and electrons are knocked loose. The electrical conductor attached to the unit forms a circuit, and the electrons can be captured as an electric current (Dhar, 2017).

While laboratory testing suggests that solar cells are usually unaffected by extreme weather (Maehlum, 2013), other factors such as light wavelength and light intensity may impact their efficiency. Silicon solar cells operate on the photovoltaic or spectral response curve, which defines the minimum wavelength as 300 nanometers (nm), and the maximum as 1,100 nm (Barett, n.d.). However, "at short wavelengths below 400 nm, the glass absorbs most of the [rays] and the [solar] cell response is very low" (Honsberg & Bowden, 2016). At intermediate wavelengths, solar cell response peaks (Honsberg & Bowden, 2016).

The Sun provides the Earth with visible light (400-800 nm), UV rays (shorter than 400 nm), and infrared radiation (IR) (longer than 800 nm) (The Editors of Encyclopaedia Britannica, 2019). Only a small portion of sunlight reaching the Earth's surface consists of UV rays, specifically UVA and UVB rays (U.S. Federal Food and Drug Administration, 2020). Still, because solar panels operate best at intermediate wavelengths, UV rays and IR are largely wasted, contributing to solar panels' low efficiency, especially in dimly lit conditions. In 2020, electrical engineering student Carvey Ehren Maigue recognized this problem. To combat it, he created Aurora Renewable Energy and UV Sequestration (AuREUS), a system which uses a fluorescent dye created from food waste (Berg, 2020). This dye converts UV rays to visible light, which solar panels can better convert to usable electrical energy (Maigue, n.d.).

At Lawrence Berkeley National Laboratory, scientists created an externally fluorescent solar cell—a cell which emits its own light using the material gallium arsenide. This rare material is a byproduct of aluminum smelting. Although gallium arsenide is expensive, only a small amount is needed to reach a "precise balance between the amount of light absorbed and the amount converted to electricity" (Franzen, 2011), thus increasing the efficiency of solar cells to 28.4% (Yarris, 2011). Various institutes have investigated ideas like these, but all have failed to find a method that brings solar cell efficiency closer to 100%.

Due to the photoelectric effect, the current produced depends on how much light strikes the module. Increasing visible light intensity can increase the effectiveness of a solar cell, a phenomenon demonstrated by concentrator systems.

II. Luminescent Solar Concentrators

Current photovoltaic concentrator systems consist of curved mirrors and lenses which direct the sunlight onto the solar panel. While these systems are effective in concentrating light and thus slightly increasing the efficiency of solar panels, they require cooling systems to prevent the panel from overheating. They also require large spaces. Therefore, although these concentrators may somewhat enhance solar panel efficiency, they may not be cost-effective (Thomson, 2008).

Due to this issue, researchers at MIT attempted to reconstruct and amplify the idea of concentrator photovoltaics. Their efforts produced an amelioration of the solar concentrator, an idea developed in the 1970s to combat high silicon prices and decrease the dependence on large solar panels (Rodarte, Hirst, & Ghosh, 2014). Luminescent solar concentrators are waveguides, focusing light waves hitting a large area and combining them, directing them at a smaller, specific target (Layton, 2008). Dye particles, a large sheet of plastic or glass, and a small solar panel make up MIT's enhanced luminescent solar concentrators, the latter two components being characteristic of concentrators on the market today. Light energy from the Sun hits the dye particles, exciting the electrons of the dye. When the electrons reach a lower energy state, they become trapped in the glass layer. The glass is sanded on all sides except for the side with the solar panel (Rodarte, Hirst, & Ghosh, 2014), so the trapped energy is directed toward the panel through total internal reflection. The solar panel captures this energy and converts it to electricity, but unfortunately only lasts three months (Layton, 2008).

While this system may increase the effectiveness of solar power, its infeasibility prevented it from being introduced into the market. Many high efficiency, photo-bleaching resistant dyes are expensive and difficult to manufacture (Franzen, 2011). Further, they may have their own chemical byproducts. These dyes are not naturally occurring, and if replaced with a more organic product, would be more efficient in reducing production costs. This project investigates exchanging this synthetic dye with a more natural element – bacteria.

III. Biofluorescent Bacteria

"Bioluminescence is the production of light by a species" (Radford, 2010). It is a type of chemiluminescence; the light is the byproduct of a chemical reaction within the organism. Bioluminescence is a cold light – "less than 20% of the light generates thermal radiation" (Evers, 2013). Most bioluminescence occurs due to a reaction between the substrate luciferin and the enzyme luciferase. While all bioluminescence involves luciferin and luciferase, some reactions occur with a photoprotein instead, resulting in biofluorescence, the "absorption and reemission of light from living organisms" (Creatures of Light | How Biofluorescence Works, 2016). A common photoprotein is the green fluorescent protein (GFP). This photoprotein was discovered in crystal jellyfish (*Aequorea victoria)*. In this specie, the photoprotein aequorin reacts with oxygen and is activated by Calcium C++. When activated, aequorin emits a blue light and activates the GFP, which emits green light (Zimmer, 2015).

Through genetic engineering, biofluorescence can be exhibited by organisms which may not naturally possess the quality. Researchers have extracted the GFP gene from bioluminescent crystal jellyfish and inserted it into bacterial DNA, specifically nonhazardous, nonpathogenic strains of *E. coli.* These engineered bacteria are plated, and those which have accepted the gene survive the antibiotic selection process. This produces a population of genetically engineered biofluorescent bacteria – these bacteria effectively produce the photoprotein GFP and emit green light when exposed to UV rays.

Researchers have investigated bioluminescent and non-luminescent bacteria as forms of energy. The company Glowee attempted to use bioluminescent bacteria in streetlamps but faced hurdles due to the lifetime of the bacteria (Marcellin, 2016). In 2018, researcher Vikramaditya Yadav, along with his team at the University of British Columbia, genetically engineered bacteria to produce copious amounts of lycopene, a photosynthetic (non-luminescent) dye (Srivastava, et al., 2018). The bacteria were then coated with semiconductor material, and glass was used as an anode (Cimons, 2018). Yadav's team combined solar panels, glass, and bacteria to produce energy, even in low-light conditions (Cimons, 2018).

Although this project uses the same key components as Yadav's, it presents them in a different form. More specifically, this project aims to genetically engineer bacteria to express biofluorescence and use these modified bacteria as an additional source of photons for a solar concentrator system. The notion of integrating biofluorescent bacteria into concentrator photovoltaics for energy production is entirely novel.

Objectives, Aims, and Expected Outcomes

This project aims to enhance the efficiency of photovoltaic cells through biofluorescent bacteria integrated into the original concept of concentrator photovoltaics, specifically investigating: Does biofluorescent bacteria impact solar cell power output when integrated into concentrator photovoltaics?

The objective of this research is to: 1) propose an alternate method of harnessing energy from solar cells; 2) assess the power output and effectiveness of said method, especially in dark conditions; and 3) examine the plausibility of real-world applications of bacteria-applied solar panels.

It was hypothesized that the application of biofluorescent *E. coli* to glass and a small solar panel in the form of a photovoltaic concentrator increases the power output of the cell during both well-lit "light" and dimly lit "dark"

simulations. Biofluorescent *E. coli* produce GFP and emit visible green light when exposed to UV rays. The application of these biofluorescent bacteria to glass ensures the visible light is concentrated, streamlining it towards the small solar panel. The solar panel can then convert this visible light into electrical energy (see Figure 1).

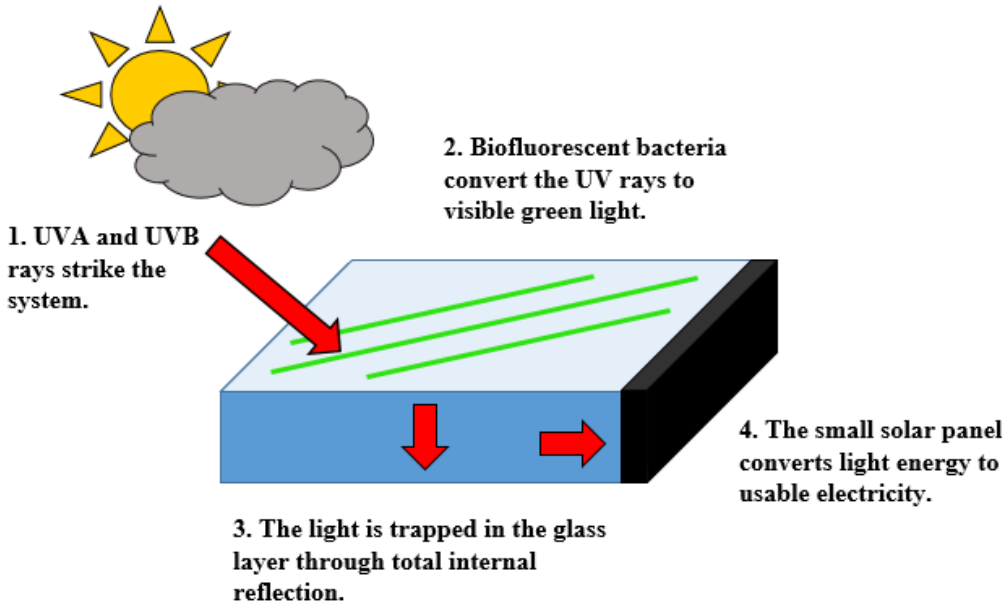

Figure 1. Biofluorescent bacteria-applied, or biofluorescent, solar concentrator model.

Methodology

In this experiment, the independent variable was the application of biofluorescent bacteria. The control consisted of the solar concentrator units with no bacteria applied. The dependent variable, or the variable that was affected by the change in the independent variable, was the power output of the solar units. Since power output is expressed in numerical form, this experiment naturally adopted quantitative data collection and analysis methods.

I. Materials Overview

Prior to conducting the experiment, necessary materials were gathered and various parts of the experiment were assembled. The Bio-Rad pGLO Transformation Kit was used to genetically engineer the *E. coli* HB101 K-12 strain using the biofluorescent pGLO gene. The finalized bacteria were plated on agar in petri dishes. To make solar concentrators, adhesive thin-film amorphous silicon solar cells were used. Each cell was adhered to a sheet of glass conducive to total internal reflection (with thickness equal to the width of the solar cell). Positive and negative wires were attached to the solar cells using a soldering gun and solder flux. To measure the power output of the cells, a multimeter and alligator clips were used.

II. Preparation of the Biofluorescent Bacteria

The preparation of agar was the first step of biofluorescent bacteria development. The agar powder provided by the Bio-Rad Transformation Kit and the listed amount of distilled water were stirred in a beaker and kept on a hot plate until the mixture was clear. The agar was then poured into the plates until the bottoms of the plates were covered and the agar filled three-fourths of the entire plate. An assistant was necessary to keep the plates steady as they were poured.

The plates were kept cold until they were used. After this, bacteria were prepared by following the instructions provided by the kit. Unmodified *E. coli* were swabbed onto the prepared agar plates using the quadrant streaking technique and incubated to promote growth and multiplication of colonies.

Genetic transformation of bacteria was achieved through the insertion of engineered DNA extracted from another organism, specifically crystal jelly, using the heat-shock method. In this method (Figure 2), an extreme temperature change puts pressure on the bacteria to accept the gene. In this case, once the bacteria accept the gene, transcription and translation result in synthesis of GFP. The bacteria express bright green fluorescence. The pGLO gene is in the form of a plasmid (shown in Figure 2), which is a circular, self-replicating DNA molecule. This plasmid can exist in *E. coli* host bacteria without disrupting chromosomal function.

Figure 2. pGLO plasmid, lyophilized, inserted into the bacteria through the heat shock method.

Ampicillin and arabinose were implemented to artificially select for the correct fluorescent bacteria for testing. While arabinose was a sugar necessary for bacterial growth, ampicillin eradicated all bacteria except the bacteria which accepted the pGLO gene. At the end of this process, biofluorescent bacteria were obtained. Using a sterile adhesive to prevent direct contact with the glass, the biofluorescent bacteria were peeled from the agar and attached to the surface of the experimental concentrators. An attempt was made to ensure that each concentrator received an equal surface area of biofluorescent bacteria to maintain consistency between the separate units. This was done by measuring the coverage of one film and then peeling an equal amount for the other cells. Multiple colonies from multiple plates were used for each concentrator to account for any differences present across colonies or plates, and to ensure sufficient visible light would be available for the solar panels. If one film had a greater surface area of biofluorescent bacteria, the excess bacteria was carefully removed using an alcohol wipe.

III. Construction of the Concentrator Units

Solar concentrator units were constructed prior to conducting the experiment. The ends of adhesive cells were cut to expose metal on both the positive and negative ends (which were labeled on the cell itself). Copper tape was applied over the exposed insides of the solar cells, serving as a conductor and as a bridge between the metal and the wires. Using a solder gun and solder flux, positive and negative wires were attached to the copper tape on their respective ends. These units were left to cool fully before use. The adhesive solar cell was then applied on the side of the sheet of glass. The control units consisted of glass, a thin-film amorphous solar cell, and an adhesive wrap.

IV. Testing

This experiment was done in a laboratory setting. There were no windows, so no outside light could penetrate the room and skew the results. For the well-lit “light” simulation, the lighting in the laboratory was

adjusted to match the lighting outside on a typical cloudless day in a suburban area. The amount of light (including UV rays and visible light) outside was measured using a light meter. During cloudless days, there is a considerable amount of UV light and a greater amount of visible light. Contrastingly, during the "dark" simulations, the effect of only UV light on the power output of the biofluorescent solar concentrator was tested for. Using adjustable UV lights and white lights in the room, these conditions were replicated in the laboratory. During the light simulation, the both the UV lamps and the white light were on. During the dark trials, to isolate the impact of UV rays on an overcast day, the white light was turned off and the UV light was turned on at a lower setting.

To test, the concentrator units were placed under the adjustable UV lamps. The control and bacteria-applied units were separated, so that the light produced by the bacteria did not reach the control units, as shown in Figures 3 and 4. Control units only had sterile adhesive material (without bacteria). The wires of the units were taped and labeled with the trial number.

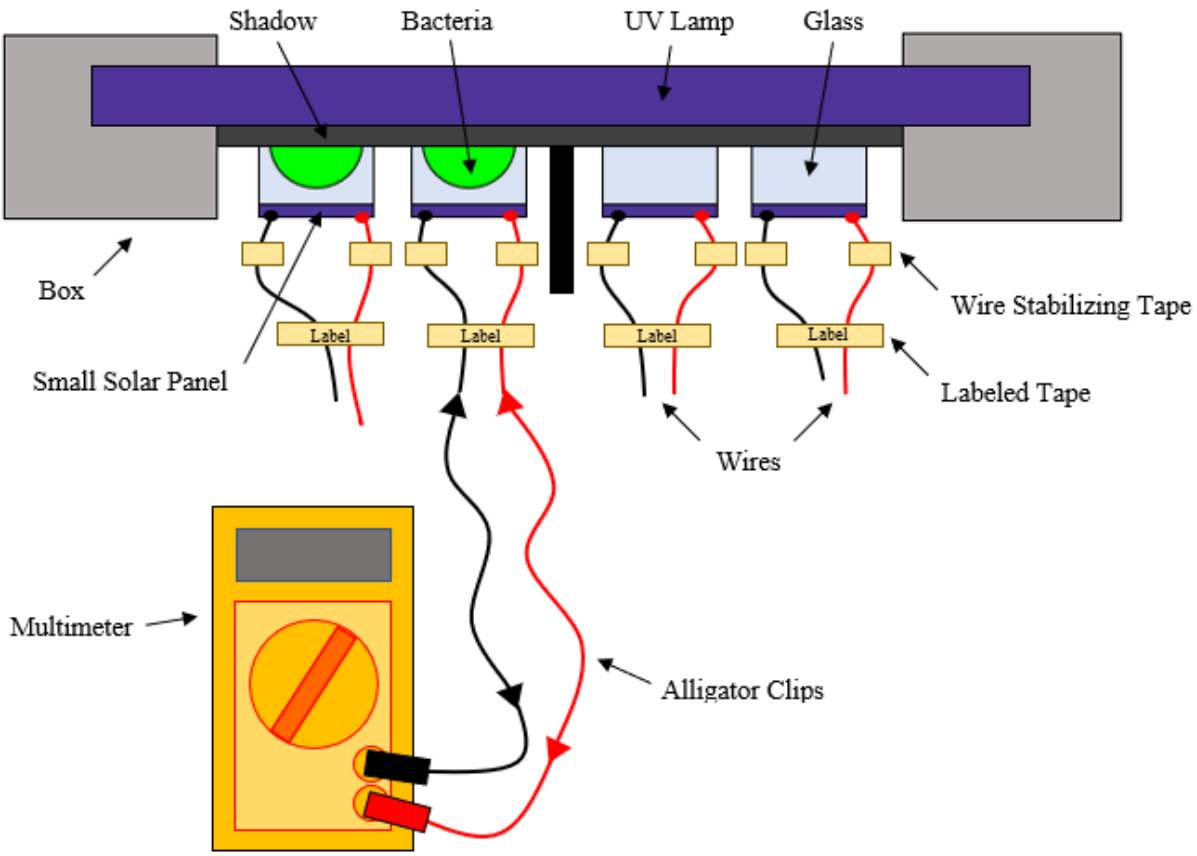

Figure 3. Experiment setup schematic.

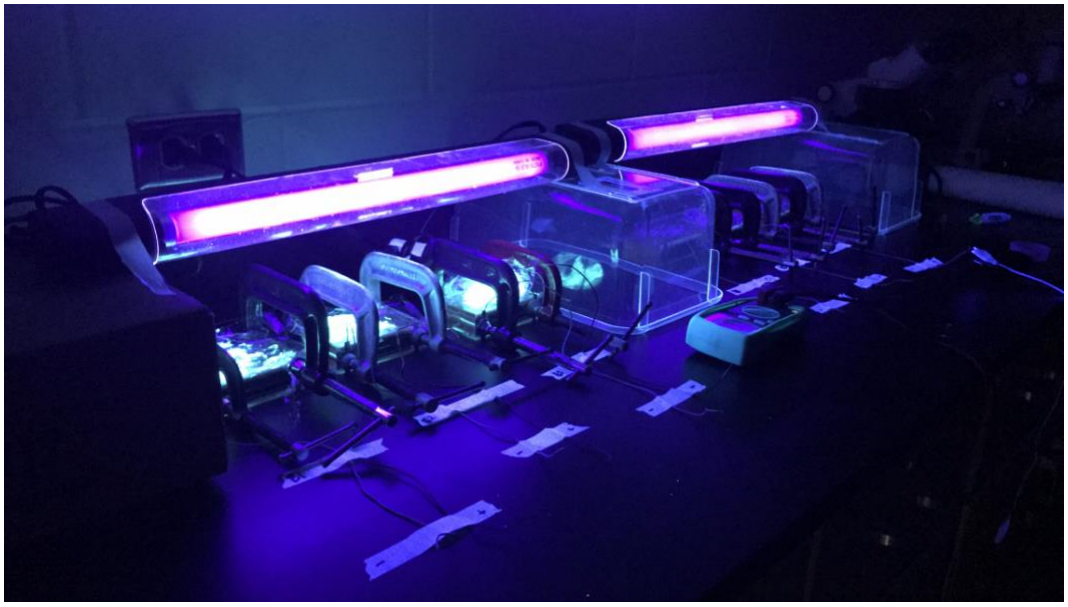

Figure 4. Preliminary setup for the dark simulation.

Clamps were used to position the units but were removed before testing. The middle plastic stand was replaced with a dark stand to ensure no visible light reached the control concentrators. Note – in this photograph, both the UV lights and the biofluorescent bacteria appear brighter than they were.

At 15-minute intervals, with a designated 15-second test time for each unit, the voltage and current were measured and recorded. Values were measured in millivolts and milliamperes due to the small scale of the system. Due to the brevity and speed of each testing time, an assistant was needed to record the values as they were measured. As Watt's Law states, voltage and current were multiplied to calculate power, and power was reported in milliwatts.

Watt's Law:

$$P = IV$$

where:

P = Power

I = Current

V = Voltage

Results

During testing, data were compiled into tables for each trial. These tables included preliminary information, such as voltage and current for each unit, which were then averaged for each time interval. These averages were multiplied to calculate power with Watt's law as previously stated. The values across time intervals were averages for each trial, and the percent increases between the control units and the bacteria units were calculated during both light and dark simulations.

There was a clear difference between the light and dark trials. During the light trials, the power output was in thousands of microwatts. During the dark trials, however, the power output was in hundreds of microwatts. This was due to the excess external light accessible in the light trials; in the dark simulation, intended to isolate the impact of UV light on an overcast day, because only small amounts of UV rays and biofluorescent bacteria were available, the overall power output of all units was lower than it was in the light simulation.

Two trials, Trials 1 and 4, were selected at random to showcase. During the light simulation test, Trial 1 showed a 61.41 percent calculated increase in power output of the biofluorescent bacteria-applied cell compared to the control. During the dark simulation, there was a 281.4 percent increase in power output. Similarly, in Trial 4, there was a 66.36 percent increase in power output during the light simulation and a 273.6 percent increase in power output during the dark simulation. These values were similar for all trials. The graphs of Trials 1 and 4 are shown in Figure 5.

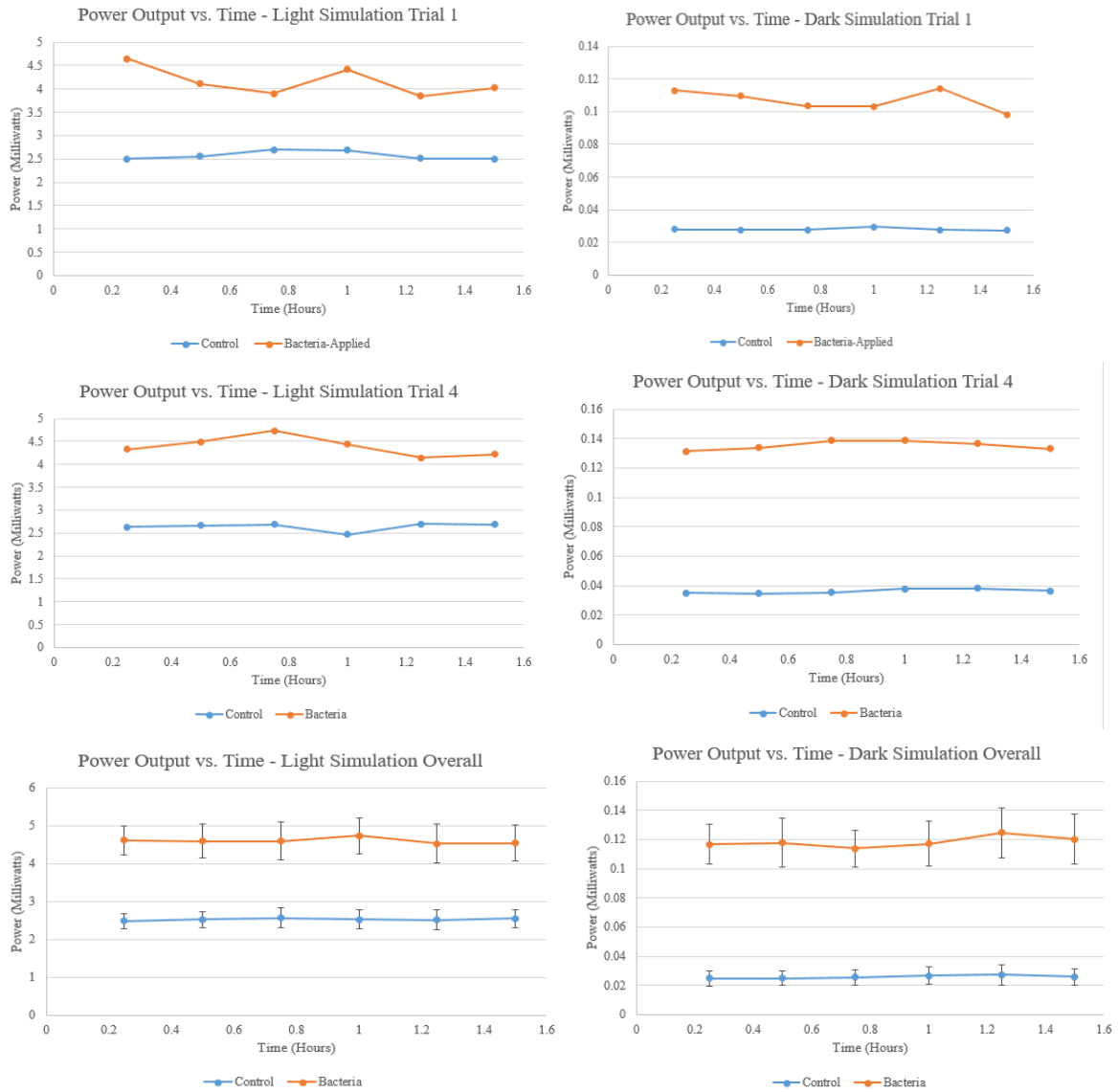

Figure 5. Graphs of Trials 1, 4, and overall.

Overall, during the light simulation, there was a 61.46 percent average increase in total power output of the biofluorescent bacteria-enhanced concentrator units versus the control units. During the dark simulation trials, there was a 275.8 percent increase in overall power output (wattage).

Although this method shows the expected outcome and a large difference between the control units and the bacteria-applied units, these preliminary charts and graphs (Figure 5) are insufficient in showing meaningful differences. A more formal, statistical system was necessary. Power was deemed the most significant unit, since supplied electricity is usually measured in this unit. This information was extracted from the original charts. To compare all power values for the control units to those of the bacteria-applied units, a two-sample T- test was conducted for the values for each trial after the data satisfied the conditions and assumptions for this test. The two-sample T-test conveys if there is a difference between two samples when the variances of the samples are not known. Because the T-tests for both light and dark trials produced p-values much lower than the significance level of 0.01 ($p = 0.000$), the differences between the power output of the bacteria-applied concentrators and control concentrators are statistically significant.

Discussion

The objectives of this research were fulfilled through the data collected. An alternate method of energy collection was proposed—while renowned institutions have previously attempted to improve the power output of solar cells, none have incorporated biofluorescent bacteria with solar cells in the form of a luminescent solar concentrator. The hypothesis of the experiment was supported. As shown through the T-tests, the addition of biofluorescent bacteria significantly impacted the power output of the tested solar concentrators. In fact, the biofluorescent bacteria increased the power output by 273.6 percent during the dark simulation, indicating that this method of energy production was effective at converting UV rays to visible light. According to the spectral response curve, silicon solar cells are effective at converting visible light, but not UV rays, to electricity (Honsberg & Bowden, 2016). With the introduction of biofluorescent bacteria, which served as the only source of visible light for the solar concentrators in the dark trials, power output increased. Biofluorescent bacteria, when used in conjunction with the glass, enables solar panels to generate power independently from any other sources of light if there are UV rays in the atmosphere. On an overcast day, when visible light may not be ample, but "up to 80 percent of the Sun's rays pass through clouds" (Sklar, 2012), biofluorescent bacteria-applied solar concentrators may be especially beneficial.

The power output of the biofluorescent bacteria-applied solar concentrators was much greater during the light trials than during the dark trials, possibly because the biofluorescent bacteria only produced green light. Green light falls towards the lower end of the spectral response curve (Honsberg & Bowden, 2016). White light, which was left on during light trials, consists of equal amounts of all wavelengths of visual light, including those silicon solar panels are most responsive to. During the light simulation trials, the presence of the biofluorescent *E. coli* increased the power output of the solar cells by 61.46 percent. This is likely because the bacteria served as a barrier, keeping light trapped in the glass layer. In future experiments, this system can be compared to a glass concentrator with a similar barrier to escaping light to isolate the impact of the biofluorescent bacteria.

I. Limitations and Extensions

To solidify the conclusions drawn from this research, further experimentation should be conducted. Although this project proposes a method to improve solar panel power output, it has limitations:

1. The orientation of the UV lamps may have influenced the results due to variations in the intensity of the light emitted from the lamps, and the different position of each solar panel could have had slightly

variable shade. However, the potential influence of this source of error was mitigated by the adjustment of the lamp location to allow balanced exposure to external light.

2. Although the bacteria are a nonpathogenic and nonhazardous strain of *E. coli*, it is commonly preconceived that all *E. coli* are dangerous to human health due to the potential of outbreaks. This may hinder the marketing of any product resulting from this research. Furthermore, the exact lifespan of the bacteria is unknown, which may also complicate the marketing process.

3. Unfortunately, because air pollution and smog decreases the amount of UV radiation reaching the ground (Climate Prediction Center Internet Team, 2019), this system may not be feasible in areas with high pollution levels. Widespread, outdoor testing is necessary to evaluate the effect of pollution levels on the biofluorescent solar concentrator.

4. Due to the small scale of this experiment, the units produced small amounts of power. It is hypothesized that the enlargement of the system would produce greater power and that the ratios of the differences between the bacteria-applied units and the control units would remain the same.

5. The differences stated above are between a bacteria-applied concentrator and a simple glass concentrator (with no fluorescent or luminescent material applied).

Considering these limitations, this experiment has numerous potential future expansions. For instance, one future experiment could test this project's concept with full-scale, industrial-grade solar panels, utilizing a real outdoor environment during a full 24-hour period. For a more direct comparison, the biofluorescent solar concentrators can also be tested against concentrators using synthetic dyes or gallium arsenide solar cells, ideas which have recently come to fruition and are not yet popular. Because the biofluorescent bacteria produced green light, which solar panels are only moderately responsive to, the effect of the color of biofluorescent bacteria on solar panel power output can be investigated. Genetically engineered bioluminescent bacteria, which utilize luciferase mechanisms instead of UV rays to generate light, may be explored as a source of visible light for solar panels at night and in areas with high pollution levels.

II. Installation Ideas

Assuming the above limitations are addressed, and this technology develops with further research, there are many ways in which this product can be installed on infrastructure. Like current solar panels, biofluorescent solar concentrators can be mounted on roofs. Still, the glass would form much of the roof, and a small solar cell would be attached on one edge of the glass. Larger biofluorescent solar concentrators may also function from fields.

Biofluorescent solar concentrators could also be integrated into windows. MIT has previously discussed the adjustment of windows to incorporate luminescent solar concentrators (Layton, 2008). The glass of the window would serve as the glass of the concentrator, and the solar cell would be embedded within the window frame. With this research, the only addition to this window would be a lightly colored film of bacteria. Because the exact lifespan of the bacteria is unknown, an automated cartridge system could be developed to change an old film of bacteria with a new one. This method would not only increase the building's surface area viable for energy production, but it would also potentially enhance the aesthetics of the building.

III. Cost Analysis

In the real world, the cost of a product is just as important to consider as the power output of the energy source. A rudimentary cost analysis (Table 1) was conducted between the current, most used photovoltaics systems, current concentrator photovoltaics, ideas for luminescent solar concentrators, and the biofluorescent solar concentrator developed through this project.

Because the bacteria can replicate infinitely on its own following its genetic engineering, the costs for production are the: space and development of bacteria farms, basic labor, and implementation. This system requires less money to be invested in the solar cell itself than other systems do, and crucially, generates power through a generally safe method. A more thorough cost analysis should be conducted in future investigations.

Comparison of Factors Affecting PV System Cost				
	Silicon-Based Solar Cells	**Concentrator Photovoltaics**	**Luminescent Solar Concentrator with Synthetic Dye**	**Biofluorescent Solar Concentrator**
Solar Panel Size	Large	Small		
Power Output	Lowest	Improved		
Space Necessary for Solar Panel	Large	Small		
Labor and Installation Costs	High			Low (Assumed)
Safety	Safe		Potentially Unsafe	Generally Safe
Associated Technologies	Solar Tracking Systems	Cooling Systems	Expensive, Unsafe, Synthetic Dyes	Inexpensive Bacteria; Cartridge System
Use	Long-Term Use		Short-Term Use (~3 Months)	Unknown

Table 1. Factors affecting the cost of various solar panel systems.

Conclusions

This project is an important step in the development and enhancement of new renewable energy technologies, specifically solar energy. The augmentation of photovoltaic cell performance through a bacteria-based biofluorescent concentrator allows for conversion of UV rays to visible light and greater power output, making them more feasible for use during both cloudless and overcast days. The application of luminescent bacteria in a sealed environment attached to the surface of the solar concentrator implies that there are a large variety of possibilities for its implementation on real-world solar panels, including in windows. This research may lead to a wider adoption of renewable energy use, reducing human dependence on rapidly depleting fossil fuels and decreasing pollution and global climate change.

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