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Integration of Silica-based Materials Within a Dye-Sensitized Solar Cell

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TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS iii

LIST OF TABLES viii

LIST OF FIGURES x

ABSTRACT OF THESIS xiii

INTRODUCTION 1

- History 3
- Dye-Sensitized Solar Cell 5
- Setbacks 12
- Reasons for Alternatives 13
- *Equisetum* 15
- Diatoms 17
- Hypothesis / Statement and Intent 19

MATERIALS AND METHODS 22

- Titanium Dioxide 24
- Glass Cells 26
- Dye 29

Page

Treatments 31

    Horsetail 31

    Diatomaceous Earth 33

    Phytoplankton 33

    Controls 33

Electrolyte 38

Sealing 38

Lighting and Temperature Control 40

Measurements 41

RESULTS 46

Statistics 46

Trials 47

Day and Night 47

Treatments 48

Day to Day Intervals 48

Day vs. Night 48

    Trials 59

Page

Treatments 59

Intervals 59

Averages 59

DISCUSSION 74

Collection 74

Day/Night Findings 74

Working Space 78

Silica Influence 79

For the Future 80

Market and Utility Integration 81

Education 83

CONCLUSIONS 85

WORKS CITED 86

LIST OF TABLES

Page

Table 1: Table of values for evaluating F-test values using means, comparing trials 50

Table 2: F-tests with least significant difference values of voltage for grouping by trial . 50

Table 3: Table of values for evaluating means via F-tests, comparing day and night 51

Table 4: F-tests with least significant difference voltage means, grouping by time of 51

Table 5: Table of values for evaluating means via F-tests, comparing treatments 53

Table 6: F-tests with least significant difference voltage means, grouped by treatments . 53

Table 7A: Comparisons of means for variance analyses between different times 55

Table 7B: Comparisons of means for variance analyses between different times 56

Table 7C: Comparisons of means for variance analyses between different times 57

Table 7D: Comparisons of means for variance analyses between different times 58

Table 8: Table of values for evaluating F-test results, comparing day time means from .. 61

Table 9: F-tests with least significant difference voltage means, grouped by average 61

Table 10: Standard table with F-test values after SAS analyses during night intervals 62

Table 11: F-tests with letter grouping for different trials during night intervals 62

Table 12: Table of values for evaluating means via F-tests, comparing daytime means .. 65

Table 13: F-tests with least significant difference voltage means, grouped by average ... 65

Page

Table 14: Table of values for evaluating means via F-tests, comparing nighttime means. 66

Table 15: F-tests with least significant difference voltage means, grouped by average .. 66

Table 16A: Voltage values analyzed for potential differences from a day interval 69

Table 16B: Voltage values to evaluate potential differences from a night interval 69

LIST OF FIGURES

Page

Figure 1: A representation of a dye-sensitized solar cell by its various steps 7

Figure 2: Current trends and efficiency performances of modern solar cell technology .. 11

Figure 3A: Photo of *Equisetum* by Robert H Mohlenbrock, 1989 16

Figure 3B: Photo of *Equisetum* by Alan Cressler, 2015 16

Figure 4: SEM imaging (x4000) of diatomaceous earth 18

Figure 5: Diagrammatic representation of our DSSC with orientation of parts inside 23

Figure 6: Photo of titanium dioxide mixed into paste 25

Figure 7: Anode side and cathode side before treatment and attachment 27

Figure 8: Cell prepared with doctor blade method of spreading titanium dioxide paste ... 28

Figure 9A: Dragon’s blood dye in a dropper bottle with filter disc to show 32

Figure 9B: Dye-sensitized solar cell with impregnated Dragon’s blood dye 32

Figure 10: Array of cells with various treatments in the cell 34

Figure 11A: Horsetail in the bio-emulsifier 35

Figure 11B: Ground horsetail after emulsification 35

Figure 12: Diatomaceous earth before placed into central zone 36

Figure 13: Phytoplankton solution on a piece of paper to show coloration of solution 37

Page

Figure 14A: View from above the cell with adhesive strip 39

Figure 14B: Side view of cell with adhesive strip 39

Figure 15A: Anode view of closed DSSC cell 42

Figure 15B: Cathode view of closed DSSC cell 42

Figure 16: Environmental chamber located at the University of Central Oklahoma 43

Figure 17: Racks specialized for work with DSSC’s 44

Figure 18A: PICO connectors with recording of voltage of DSSCs 45

Figure 18B: Image of system reading DSSCs via PICO system 45

Figure 19: Distribution of overall voltage from all three trials via boxplots 49

Figure 20: Distribution of voltage values separated by day and night 52

Figure 21: Distribution of voltage as a value to different treatment groups 54

Figure 22: Distribution of daytime means and average voltages between the trials 63

Figure 23: Distribution of nighttime means and average voltages between the trials 64

Figure 24: Distribution of daytime mean voltage values between treatments 67

Figure 25: Distribution of nighttime mean voltage values between treatments 68

Figure 26: Distribution of daytime mean voltages for all cells across ten days 70

Figure 27: Distribution of nighttime mean voltages for all cell across nine days 71

Page

Figure 28: Daytime mean voltages for each treatment average from all three trials 72

Figure 29: Nighttime mean voltages for each treatment average from all three trials 73

ABSTRACT OF THESIS

University of Central Oklahoma

Edmond, Oklahoma

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ABSTRACT**:**

Dye-sensitized solar cells (DSSC) are a potential model to help aid in potential steps in solar energy efficiency and progress. However, measures taken have resulted in costly methods and a lack of supply in various materials, such as dyes, electrolytes, sealants, and glass – adjustments. The research team, led by Dr. Bidlack, has tackled various parts of the DSSC model to determine potential avenues of research and progress; the most recent method involving integrating silica or silica-heavy materials into a cell and evaluating its effect over time. For solar cells, light interactions are key to exciting electrons that eventually carry energy through the gradients within. We suggested that if light reactions could be utilized within a cell, an increase in potential light "hits" may increase the overall values of our previous models. The treatments groups for our silica-integrated cells included diatomaceous earth, phytoplankton, and horsetail extract; along with two control groups without treatments. Reasons for these chosen groups were to use non-costly materials and readily available materials that various countries and cities could obtain without major losses, as well as replacing methods and materials that bring could harm the environment from several angles. A general linear model (GLM) and ANOVA compared treatment groups with least significant differences in various combinations and variables. Data from three trials suggested that treatments with either horsetail or diatomaceous earth responded similarly across a ten-day period, and the physical influence of such materials. Horsetail-based devices had an average voltage of 155.71 mV and diatomaceous-earth cells reported an average of 138.75 mV during light intervals. Control cells without modification had averages of 63 mV (with dye) and 22 mV (no-dye). Our results suggested promising and interesting effects with silica-based resources along with potential ventures with these and similar materials. Light absorption and voltage may be enhanced by both silica, chlorophyll, and the physical nature of such materials. An experiment of this design has not been published and we believe that meaningful steps were taken with the progress in this research.

INTRODUCTION

Use of light energy and the conversion into sustainable, usable energy has progressed for decades (Vullev, 2011). Solar energy in the last half-century has become an innovative field to supply accessible energy without many of the major contributions to energy-induced pollution (Su'ait et al., 2019). Materials for older sources of energy are becoming less available and less favored due to a myriad of factors that cover levels of inefficiency. It is estimated that by 2050, demand for electricity is expected to double or triple with advancements in technologies taking place (Cari et al., 2014). Climate change alone is pushing this demand and stress for solutions and resources that remain (Wu et al., 2008; Iftikhar et al., 2019). Emulation of natural cycles, or also known as biomimicry, can supply smaller scale products to either reduce negative solutions on the environment or improve knowledge on the same systems or undiscovered interactions, humans can utilize (Vullev, 2011). Over the course of history, humankind has redefined how energy and light from the sun can be harnessed, from utility in farming to weaponry in the early times. The sun has been noted as a utilized resource since 287 BC with its utility as a weapon against ships that used mirrors focusing light to a point (Hidalgo et al., 2018). Socrates provided information on housing placement in relationship to the sun to manage temperature control with the sun’s orientation (Hidalgo et al., 2018). The last century has focused mostly on solar energy projects involving heating and cooling of buildings, concentration and distribution of electric power, and energy conversion for industrial purposes (Hidalgo et al., 2018). Renewable energy is defined as energy sources from continuous natural cycles like sunlight, wind, hydro, rain, waves and geothermal heat (Su'ait et al., 2015).

Accessibility to renewable energy sources has continued a trend of exclusiveness for many developing countries, such areas that use methods that are used for availability of biomass (Chirambo, 2016). With a crisis, like COVID-19, that separates countries from import or exports either out of reduced workforce or cost of fuels to export or import (Hosseini 2020), solar energy may be the field to find the means to supply accessible energy without many of the major contributions to heavy costs, utility induced pollution, and low to non-toxic emissions (Veerappan et al., 2019; Hosseini, 2020). Much like the depletion of available gas and oil reserves, best resources are limited for utility at the current rate of consumption (Moriarty and Honnery, 2020). Non-biomass sourced energy demands are expected to increase as world population is said to reach almost ten trillion by 2050 (Moriarty and Honnery, 2020). Many renewal energy models will use reasonably costed materials, though the work to the make the model is harder when working at a larger scale. A draw to solar power is the potential reduction of prices on the consumer in overall utility from their local system and a relief of pollutants that consumption of gas and fuels contribute via products (Hosseini, 2020).

Research has evaluated the implementation and potential of wind and solar energy to bring relief to grid systems as demand increases (Kumar et al., 2016). The scale of large implementation to the more efficient models or an abundance of space for utility is very costly with what would be premium and most efficient for public use (Mariotti et al., 2020). COVID-19 has brought doubt and difficulties for the discussion and implementation of renewable strategies when the support is lost with economic decline (Hoang et al., 2021). Convincing and influencing of policy makers to devote resources into renewable sectors are at a low with a current interest for solar still shallow and low supply of funds to appoint to possible ventures (Hoang et al., 2021). Issues that have plagued such models involve the integrity of components such as electrolyte or other chemical or physical components. This could contribute, now or later, to ecological problems associated with the breaking and fragmentation of harmful materials onto a fragile environment (Tsoutsos, 2005). Some heavily utilized solar cell materials use metals that could leach into water sources, and such efforts to reduce this effect upon the environment include using spaces that are low conservation cost, importance, and fragility where potential fragmentation cannot overly damage protection efforts (Cameron et al., 2012). Positive uses of renewable solar energy materials do indeed help the process of reduce greenhouse expulsion, though worries include integrating large solar energy projects on public/private lands that may disrupt the current historic usage and potential conditions of habitats directly and indirectly (Tsoutsos, 2005). Projects need an understanding from all parties as to not infringe on cultural practices, nor support actions that would disrespect the integrity of sacred and fragile systems (Brostrom and Svahnstrom, 2011). Eco-awareness and responsibility are priorities in the efforts of establishing better technologies that create lower waste and lesser incidents on wildlife systems, while improving the health and welfare of communities struggling with access to energy (Haryanto et al., 2014).

History

Modern photovoltaic research did not take off until the 1950s, though records go back to 1830s with experimentations of photoconductivity and the general photo-electrochemical process (Spanggaard and Krebs, 2004). Replications and alterations of photosynthesis opened a vault of contraptions that could mimic various pathways of how organisms could and may obtain energy for survival. Biomimicry may be essential for understanding what other methods available resources can be used for or transformed into for purposes of sustainable usage. The implications show where and what may be the answers for cheap, renewable energy. Though exact mimicry may never be possible artificially, inspiration from all or parts of a process still are crucial for progressive solar research (Vullev, 2011). Models can refine and evaluate principles that not only shape a single process but can unify the existence of many, and if such a model can successful use cheap, affordable resources, then more options can be observed and manipulated for open access to renewable energy (Subramanian et al., 2018). The price gap may always exist for materials, but nonetheless an effort for alternatives is crucial to changing a standard on solar science academia and industry. Such models can solve this same very crisis, though understanding exactly why solar cells still face this problem with incentive is similar across all levels of solar devices.

Photosynthesis is described as the process of transforming photon-excited light to create a source of energy for that organism to either store or utilize. Light excites pathways of chemical catalyzation to promote an ionic channel for reservoir molecules to become altered into a useable state for other systems to manage. In plants, pigments play a key role in the spectrum of light absorbed that best facilitates what is ideal for that organism. Natural selection has driven utility of one pigment over another based on the conditions set upon the organism and its surroundings. The evaluation of plant-energy mechanics has been helpful for scientists to decide how small molecular differences effect the efficiency of a substrate to transform what is absorbed into a final product. Rebuilding and replicating processes in life has led to the progression on current methods to improve our approach to utility and understanding. The process of reorganizing the systematics of photosynthesis and fully interpreting what potentials exist influences the pace of emerging photovoltaics (Faunce 2018).

Dye-Sensitized Solar Cell

The 1990's brought along what was a major moment for dye-based photovoltaics. The creation of the dye-sensitized solar cell (DSSC) by Grätzel and O'Regan met the standard of what renewal energy hoped to provide (1991). In its conception, the materials provided a reliable gradient for electricity to move from one side of the cell to another. The gradient and drive of electrons is stimulated by the natural properties of such semi-conductive materials and photo-sensitive dyes accompanied with an electrolyte. A cell that can recycle electrons through cheap, non-toxic and safe procedures could prove to enhance and inspire further experiments in solar technology. A common pair of problems for many machines is its stability and integrity (Gong et al., 2017). Integrity of these cells have been somewhat difficult without using materials that are more industrial and potentially harmful in use, like refined silica, or synthetic toxic dyes. The central system of the cell must remain mostly intact for it to be a potential source of energy flow. Adjustments to this central reaction zone have been done in a variety of experiments to assess and fortify this relationship between parts (Gong et al., 2017).

The dye-sensitized solar cell (DSSC) was inspired by photosynthesis using the resources mentioned prior, and since its inception has remained a pillar in efforts of creating solutions for sustainability and compatibility to an ever-changing environment (Etgar et al., 2013). Early on before its inception, DSSCs were believed to not work under early assumptions of a weak, non-smooth gradient, nor heat stability (Hagfeldt et al., 2010). Modern builds use TiO_2 as the semiconductor, since prior work from O'Regan and Grätzel’s 1991 study, who commended non-toxicity and an affinity of dye absorbance (Rho et al., 2013). As shown in Figure 1, the cell is composed of two halves: the cathode semi-conductor side and an anode side that is layered with an aggregator of connective, catalytic molecules, such as platinum or graphite (Nazeeruddin et al., 2011). These two parts are the bridge to the reactions that initiate the transfer of electrons from gradients. The closest research specific to DSSC-like utility began back in the 1860s with records of electricity conduction through the relationship between a photosensitive dye and an electrochemical cell (Rokesh et al., 2014; Sharma et al., 2018). Since then, it is major milestone DSSC model remains as a standard in the efforts of creating solutions within a growing demand and stress on ecosystems, while both sustainable and affordable. O'Regan and Grätzel's work documented successful creation of a cell that held formidable energy efficiencies in both natural and simulated light (1991). The model DSSC contains four central components necessary for full functionality: a working electrode, a photosensitizer (dye), electrolyte (redox mediation) and the counter electrode (Sharma et al., 2018). The combination of the prior pieces resembled similar parts to the working foundation of photosynthesis, and thus utilized by a constant forward movement in electronics and sustainability.

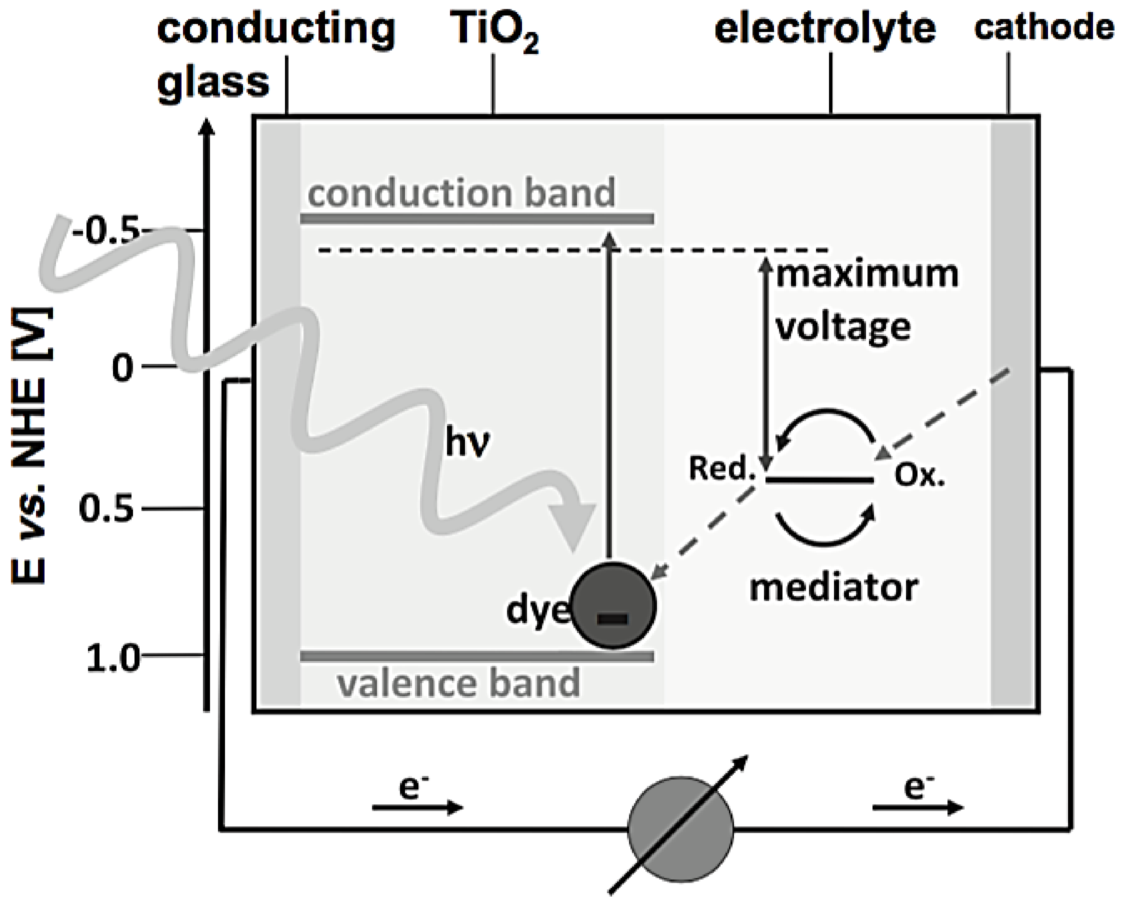


Figure 1. A representation of a dye-sensitized solar cell by its various steps and components (Nazeeruddin et al., 2011).

The reaction begins as light contacts the working electrode semi-conductive layer and into the dye (Kim et al., 2004; Haryanto et al., 2014). This excitation moves electrons in the dye to an excited state and pushed into the TiO_2 layer (Kim et al., 2004; Haryanto et al., 2014). Electrons are carried through an external load and to the counter-electrode (Lee et al., 2011). An oxidized dye recollects electrons via the redox pathways of iodide/triiodide, where it replaces missing electron from the tin-coated-oxide (TCO) coated counter electrode (Gu et al., 2017; Ifikhar et al., 2019). A working electrode contains a thin layer of a semi-conductive metal oxide that has a wide band gap for great solar incidence and electron facilitation (Haryanto et al., 2014). TiO_2 has been somewhat of an industry standard, for its affordability, availability, and non-toxicity (Rho et al. 2013). TiO_2 also can absorb most organic dyes and synthetic dyes for such models (Sharma et al., 2018).

A dye or any photosensitizer facilitates the initial electron excitement from photo incidence and energy from a light source (Kay and Grätzel, 1993; Haryanto et al., 2014). When selecting for a dye, criteria must be met so that electrons entering and exiting from orbitals must interact with the redox reaction in efficient electron regeneration and location of orbitals in electron acceptance can work at its best (Hagberg et al., 2008). The best performance dyes are ruthenium based within a monolayer on the semi-conductive layer (Haryanto et al., 2014; Ifikhar et al., 2019), though organic dyes from plants have been investigated to observe efficiencies in cheaper solutions (Cari et al., 2014). Ruthenium is expensive due to low natural abundance and is caustic in excessive exposure. Many dyes are also found plants and algae, though some find trouble with binding to TiO_2. Overall, many chlorophyll and similar groups, can influences absorption of light in solar cells (Kay and Grätzel, 1993).

The anode seals the flow as electrons cycle through varying orbital occupancy (Rokesh et al., 2014). Two electrodes connect and are the bridge to the electrolyte and dye reactions that are responsible for the initial light-started reactions in collecting values of energy. The electrolyte, dye, and light conduct reduction and oxidation cycles that promote energy generation and transfer across the gradients within. Electrons from the dye are excited by light to their most excited orbital, followed by the return to a native stable state by the release of energy. Values associated with reading a DSSC are in millivolts (mV) and are connected to a reading device like a battery, one wire each connecting to the cathode and anode plate. Transparent conducting oxides used in these cells have many free electrons that are beneficial for the efficiency of the total cell and are economically efficient versus utilizing costly compounds as in other larger models (Rokesh et al., 2014). All these pieces need to have stability to a myriad of effects that deter the cells' abilities to function properly. Adjustments to improve the model come at a cost of the materials or its accessibility to the larger market.

The scale of solar cell work has expanded to discover means for large production to make up for low efficiency in energy transfer and utility. The solar cells today are becoming more complex and convenient in both form and function. Growth of a sustainable market stems heavily on the affordability and ease of installation and upkeep without costly maintenance, or even potentially environmental consequences (Sharma et al., 2018). Though crystalline silicon (Si)-based photovoltaic systems dominate the current market due to many of their features and higher efficiency values, the overall build cannot suffice in low intensity light environments and the pre-work required to refine silica. New photovoltaic technology utilizes expensive protocols that repurpose silica thus increasing the cost of utility (Mozzafari et al., 2017), and as mentioned prior the demand for these systems has been met with low confidence in the potential of new solar energy efforts (Hossieni, 2020). A recent review by Mater (2021) on the research trends for DSSC and similar voltaic systems discussed that several components of these cells are valuable to the accessibility of further research and implementation into practical and large-scale use for nations all over. The diversity that exists for what solar energy is useful for and what it is necessary for highlights the push to expand even further on efficiency, durability, and accessibility to the larger market. Figure 2 represents the trend of research-cell efficiencies for multiple types of cells since the 1970s (NREL, 2021)

The evolution of the DSSC has been an enlightening experience, where some scientists have moved to develop a more ergonomic form, than efficient function and vice versa. Many cells like DSSCs provide a simplistic and somewhat affordable means to transform energy, though where and what exactly these cells are destined to be used for is up for debate. Only until the issues that have kept DSSCs from industry standard will the world see potential. Many endeavors focus on the increase in efficiency of the unit via additions both in and outside the cell. The lifespan of a cell is dependent on the stability of interactions that allow electricity to flow in the first place, both form and function. Accomplished by modern science is the push to build upon what applications the various photosynthetic models exist and how either simple or complex reconfigurations can or cannot provide the step into marketability.

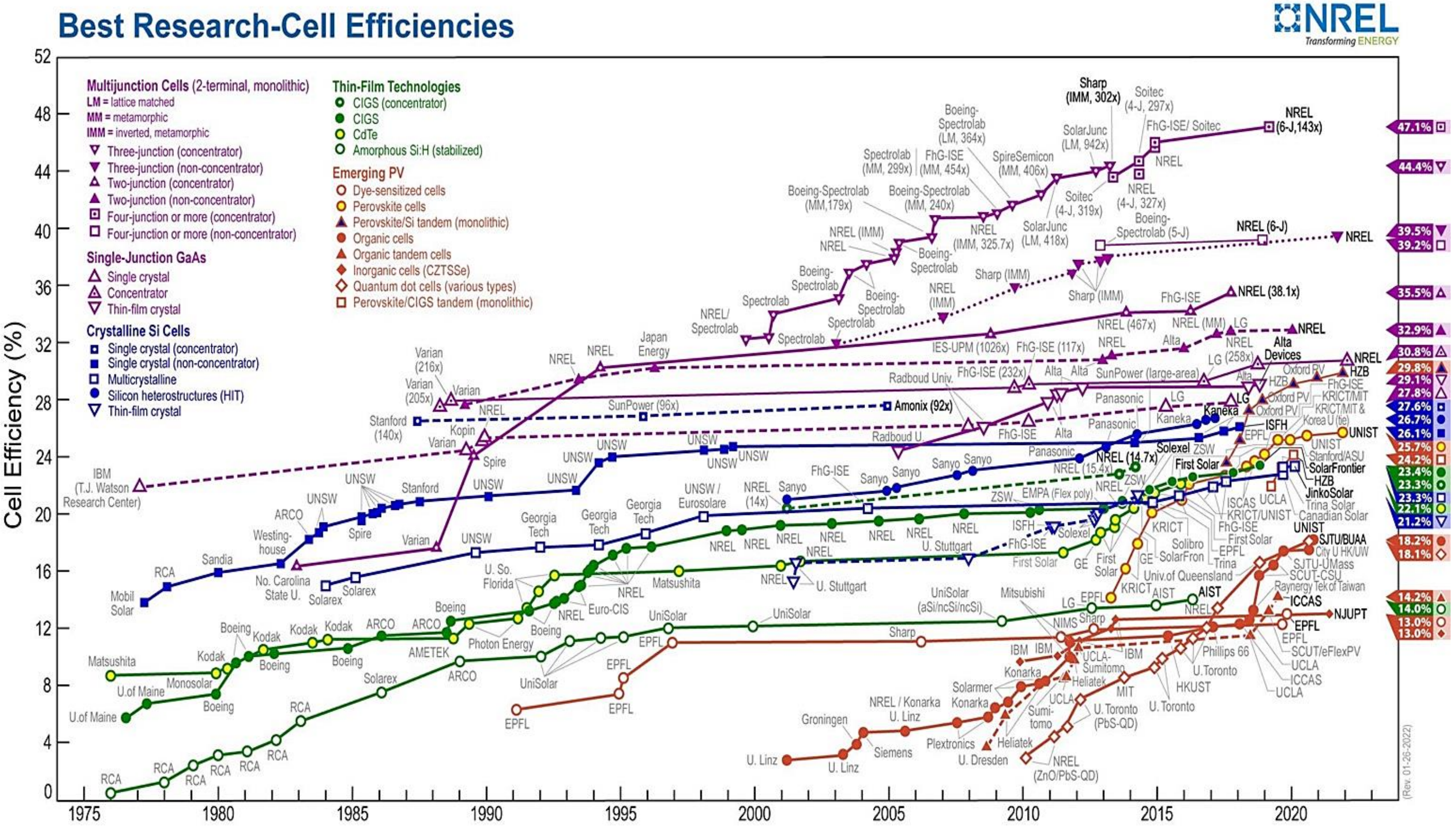


Figure 2. Current trends and performances of modern solar cell technologies since 1975 to 2021. Courtesy of the National Renewable Energy Laboratories (2021).

Setbacks

Issues for most solar cell technology involves the small to large pieces that may have a negative impact alone or as a unit. For DSSCs, the problems for large scale utility involve the leakage of the electrolyte solution or the destruction of glass parts (Zhao et al., 2014). Methods to remedy these issues include finding means to better seal the cell, improve the integration and insertion of the electrolyte solution, and modify components that will not cause oxidation or disintegration of the electrolyte or other cell components. Attempts to contain the electrolyte solution include entrapping the liquid into a polymer, binding it within to interact with its components in the cell (Zhao et al., 2014; Su'ait et al., 2015). Solid-state cells remove all liquid and semi-liquid materials so to promote a non-leaking cell that still permits electron flow (Zhao et al., 2014). Setbacks include limited knowledge on potential effects on ecology and health of flora and fauna, and a lower conductivity affinity than the liquid counterpart (Su'ait et al., 2015). Intentions to remedy this issue have been underway, and applications to moderate the interaction mimic the roles of the polymer in DSSCs. Cellulose may indeed be a candidate for polymer-based bridges with the help of modification that enhance conductivity (Salvador et al., 2014). Changing the physical conformation, such as making a polymer spindle, has been seen to have some increased efficiency and lifespan with such modifications (Zhao et al., 2014). Mater (2021) reviewed how electrolyte alternatives may be a practical place to start with adjusting the DSSC model, where copper (Cu) redox electrolytes have shown impressive performance under direct and artificial sunlight through overall energy conversion. However, such metal compounds may lead to corrosion and disjunction between liquid and solid components.

Metals like gold infused with silica have a pronounced effect on cell efficiency, and thus should open further investigations into other aiding metals in electron injection and stability (Törngren et al., 2014). Synthetic compounds like polymers have been studied as a mode for an electrolyte to be integrated in the cell, where metals are melted into the polymer and influence flow of electrons (Kim et al., 2004, Etgar et al., 2013). This approach is to reduce leaking of the components, especially the liquid electrolyte responsible for electron redox. Gu et al. (2017) investigated methods to preparing electrolytes and what variables are most significant in its integration, including the viscosity and the solvents that are used (organic versus inorganic compounds). The fluidity and malleability of the electrolyte could be enhanced with materials to promote conductivity, like salts, or control such reactions to maintain stability with viscosity (Bella et al., 2015). This is promising as a dynamic ingredient for both the indoors and outdoors, though more work should be done to address eco-safety of such metals exposed to the public.

Reasons for Alternatives

The negatives of efficient dyes, like ruthenium-based dyes remain as an expensive product and still somewhat volatile and harmful to exposed wildlife or humans (Grätzel, 2003; Grätzel, 2005). Alternatives currently being evaluated involve the use of natural dyes in DSSCs, including chlorophylls, anthocyanins, and beta-carotenoids (Cari et al., 2014). Organic dyes from natural sources should be heavily favored as safer, cheap, and stable as a component on the semiconductor (Hamid et al., 2018, Suleria et al., 2020). Cheaper solutions could replace today's best solutions via availability and ecological safety. It will remain important that integrating solar technologies into the environment can have negative effects on vegetation as part of installation, potential leakage into water systems, and may require levels of upkeep that may disturb natural cycles (Rabaia et al., 2021). Modern electronics utilize materials that can imprint the materials necessary for energy to traverse and be controlled. Many such materials have held ground as industry standards for public models, and such materials should be assessed in other places to evaluate their role in other projects. Once such material is one of the most abundant materials available and is an element/compound that many organisms have incorporated into their own systems.

Silicon is a well-abundant element with semiconductor qualities with a history of integration in several technologies. The conformation of atoms and band-gap characteristics makes silicon and its oxide form, silica, useful in temperature variable conditions, thus a moderately stabile component for outdoor solar cells. Its texture has been evaluated in observations within natural utility. Rho et. al (2013) evaluated the potential of silica aiding in light scattering, where silica beads are integrated into the working electrode and showed signs of influence on efficiency. Silica is abundant in terrestrial and aquatic locations, utilized in various plants and alga. Silica sinks can also serve as a location for understanding silica and its effect in the ecosystem. The absorption of silica and its utility in plants has been mostly associated in structural integrity and some disease resistance (Batchelor et al., 2012). The purification of this silica product has large implications in medicine, textiles, and technology (Batchelor et al., 2012). In technology, silica can be fixated for multiple roles and has the benefit of being non-toxic in such circumstances. Silica can be altered and fixated using electrolysis and molten salts (Homma et al., 2015).

One team has investigated the effectiveness and efficiency of DSSCs with silica-coated nanofibers impregnated into the core (Sherafati–Taberestani and Samadpour, 2019). They saw an average of 4.76% efficiency in energy conversion, approximately 120% above their normal untreated DSSCs. Silica acted as a conductive support system within the matrix of the cell, helping electrons travel through the electrodes. Outside of solar focus is the work with silica in a variety of other electronic devices, and what future could be done to move towards more of its utility (Laskowski et al., 2019). Overall, silica's cheap accessibility and interesting qualities will continue to make it an admirable resource in renewal energy efforts.

Equisetum

One silica-based source that has shown promising applications in science is the genus of *Equisetum*, more commonly known as horsetail, shown in Figures 3a and 3b (Law and Exley, 2011). *Equisetum* can be found worldwide and has a diverse distribution. *Equisetum* generally grows in low pH environments and has a natural resistance to many heavy metals (Erika et al., 2014). In fact, research suggests more work to be done to see if *Equisetum* might be a possible resource for the aid in the remediation of habitats exposed to harmful metals (Erika et al., 2014; Qihe et al., 2017). Silica, along with other compounds are absorbed by the plant from soil and water extraction, where it becomes integrated to the stem and leaves of the plant (Law and Exley, 2011; Gonzales et al., 2020). This provides a buffer for the absorption of other materials and helps stabilize certain portions of the plant it incorporates metals into (Gonzalez et al., 2020). *Equisetum* spp. have been evaluated in the medical world as a historic supplement and herb (Qihe et al., 2017).

Figures 3A and 3B. (A) Photo by Robert H Mohlenbrock, 1989, *Equisetum arvense* L.; (B) Photo by Alan Cressler, 2015, *Equisetum hyemale*.

In medicine, attempts to observe medicinal qualities and a history of herbal applications have been conducted (Schippmann et al., 2002; Monteiro et al., 2018), with one study evaluating the potential of horsetail-based ointments for inflammation and midwifery procedures (Asgharikhatooni et al., 2015). Chen et al. (2020) saw interesting results from integrating silica from *Equisetum arvense* into a lithium battery. Its multidisciplinary functions and cheap access make its utility more valid in establishing cheaper and more abundantly available products. Demand for such properties will continue to increase as lower economically prevalent lands continue utilizing more solar technology in poorer communities (Schippmann et al., 2002).

Diatoms

Diatoms and desmids are aquatic microorganisms that have also utilized silica absorption in aiding light focusing during photosynthesis and as a structural component of their shells or frustules (Calvert et al., 1930). These organisms retain absorbed silica and other metals, then had settled in a form of fossilized and aged composite known as diatomaceous earth (Calvert et al., 1930; Reki et al., 2021). The diversity of these shells depends on the metals and minerals from their time and geographical location, influence shape and function for these remnants of biological life (Calvert et al., 1930). Diatomaceous earth (DE) is about 89-91% silica with significant amounts of both aluminum oxide and ferric oxide (Tsai et al., 2006; Reki et al., 2021). Figure 4 from Tsai et al. (2006) shows the intricate morphology of the frustules. Once processed and sold on the market, there is utility as a non-toxic insect repellent for houses and garden (Quarles, 1992), insulator in materials, and supporter in catalytic reaction (Tsai et al., 2006).

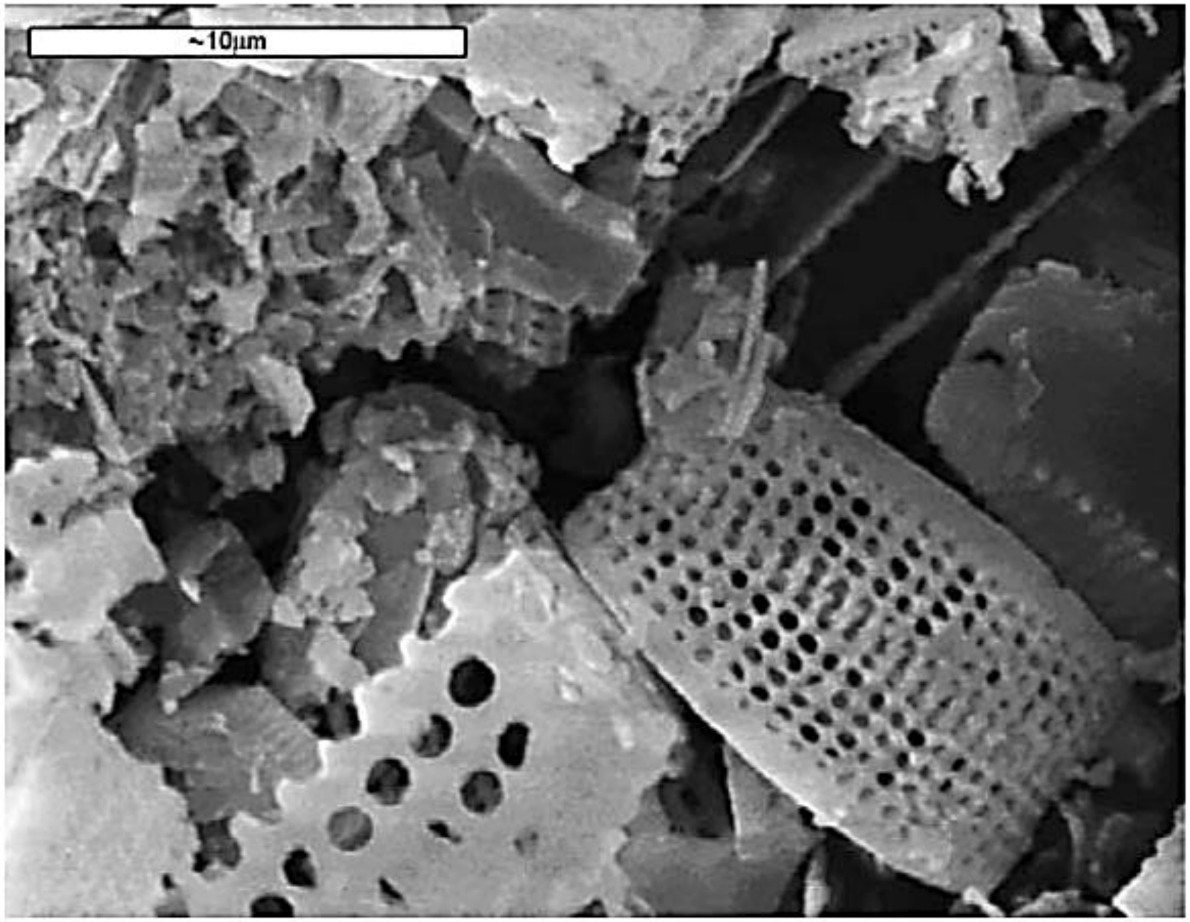


Figure 4. SEM imaging (4000x) of diatomaceous earth (Tsai et al. 2006).

No work has currently been done in solar technology with diatomaceous earth (DE) without modification, most likely due to its rigid nature and potential to compromise the interactions upon the working electrode, though methods to alter it into a readily purer form for potential utility (Bessho et al., 2009; Izevbekhai et al., 2021; Reki et al., 2021). What may make DE a viable component in DSSCs is the concentration of silica and DEs shear abundance. Its absorbance potential is worth time to research, where one such case looked at the potential capacity of fluoride absorption from hyper-fluoridate waters in Africa (Izuagie et al., 2015). The non-toxic nature to humans and larger animals makes DE a formidable component to evaluate, as well as a level manipulability that is available for such a basic and cheap resource. Though minimal now, the risks and safety that existed back in the earlier 1900s could not control dust and inhalation of DE at such mills, and along with other persisting issues has been significantly reduced. Checkoway et al. (1993) investigated the health and mortality of DE mill workers exposed to higher-than-normal levels of crystalline silica and discovered a low associated risk in the presence of good ventilation.

Hypothesis/Statement and Intent

The focus for this research looked at what could be used to replace, or be replaced in the face of less available resources and an increase in demand for alternatives in DSSC components. The materials in use are ones that come easily and in theory have a chance to enhance the performance of this and other models. DSSCs containing low-risk, low-toxic materials that are manageable to clean and dispose of without self-harm or harm to others, should help motivate more efforts with this module. The budget for materials was limited to $500 US dollars, thus preventing use of expensive synthetic dyes. Cheaper materials may motivate more individuals to approach this model and potentially be responsible for the next major steps forward. COVID-19 as a pandemic challenged this and other similar projects to make do with the most available and the least volatile to find missed avenues of modification to the cell. An experiment that can evaluate the potential uses of more readily available silica resources within the confines of a dye-sensitized solar cell was the intention. Raw horsetail will bring forth a discussion on the interactions between the introduced dye, the pigments already within the horsetail, and the qualities of SiO2 as energy is carried and transformed. Treatment groups provided should analyze specific differences in the composition of the cell matrix and should highlight how this apparatus can adjust for such.

The Bidlack research group has worked with photovoltaic cells for more than a decade with the goal of observing meaningful applications of natural materials that may be an essential change for DSSC solar cells onward. Components of a DSSC are interchangeable if electron flow and transfer are compatible with the compounds used. Past experiments from FitzSimmons (2010) have included integrating chloroplasts from varied species of plants into a cell as a buffer for energy conduction. The study by Jones (2015) focused on utilizing budget friendly resins and dyes, such as Dragon's blood, *Daemonrops draco* Blume, to replace the extremely hard to come by ruthenium-based dyes that exceed $500 USD/gram. For both experiments pros and cons existed for this replacement and were able to discuss how such replacements could be beneficial in their own rights to access and efficiency. This research involved adding to the cell a secondary layer of natural silica from cheap, readily available materials like *Equisetum*, diatomaceous earth, and phytoplankton. The reasoning for the addition was to evaluate what the microscopic structure of the silica and whether its semi-conductive nature would either hinder, promote, or not affect the system within the DSSC under the same conditions as the previous works.

Silica in this purpose has been used for other models, but nothing of this model's simplicity. This project aimed to understand what silica may do in potential interactions with light scattering within the central matrix. Photons may be reflected off the refractive surfaces of micro-silica elements and thus help light from being lost along with the energy it creates. Issues with unrefined silica stem from the rough, amorphous nature that requires minor to moderate modification before applications. *Equisetum* could be a suitable source of silica, along with the diatomaceous earth and phytoplankton. As with most components in solar cells there exist many more options that may fit in this particular model of the solar cell, the focus was on efforts to use cost-efficient supplies that are naturally abundant and present. With these issues, the assumption was that the various silica sources could buffer conductivity and aid in prevention of leaking from within the cell. Cheap and available replacements may improve efforts of further research with DSSCs and similar cells to promote a further eco-friendly agenda, and a pursuit to alternatives in resource restrictive times.

MATERIALS AND METHODS

Research was conducted within Howell Hall at the University of Central Oklahoma at end of 2019. Efforts to create a cell by first ensuring that leftover stock from prior experiments to conduct preliminary trials before final recordings was available. Solar cell sheets had been previously purchased from DyeSol, a company dedicated to provided instruments for solar electronic research, pre-treated with fluorine-doped tin oxide (FTO). Titanium dioxide and electrolyte solution were purchased with the help of the school, although both materials are purchasable and very accessible. Diatomaceous earth, horsetail (*Equisetum spp*.), and phytoplankton all were purchased through online Amazon marketplace aggregates, all publicly accessible. Choices for purchases reflected a goal to utilize very accessible and affordable materials when best options have an unreachable price tag. Basic protocols for concocting a paste and data recording are based on methods used from previous works from the Bidlack Research lab, such as FitzSimmons (2010) and Jones (2015). Work will continue to utilize the simple and complex moments of photosynthesis and the biomimicry in ways that the public can understand and potentially implement.

The DSSC model along with the intended alterations can be seen on Figure 5. Materials to be analyzed will be placed inside the central area where it can interface with the conduction substrate (titanium dioxide), a dye, an electrolyte, and the cathode bridge. Application of silica-based materials was influenced by how light enters into the cell, and how well components stack inside the core.

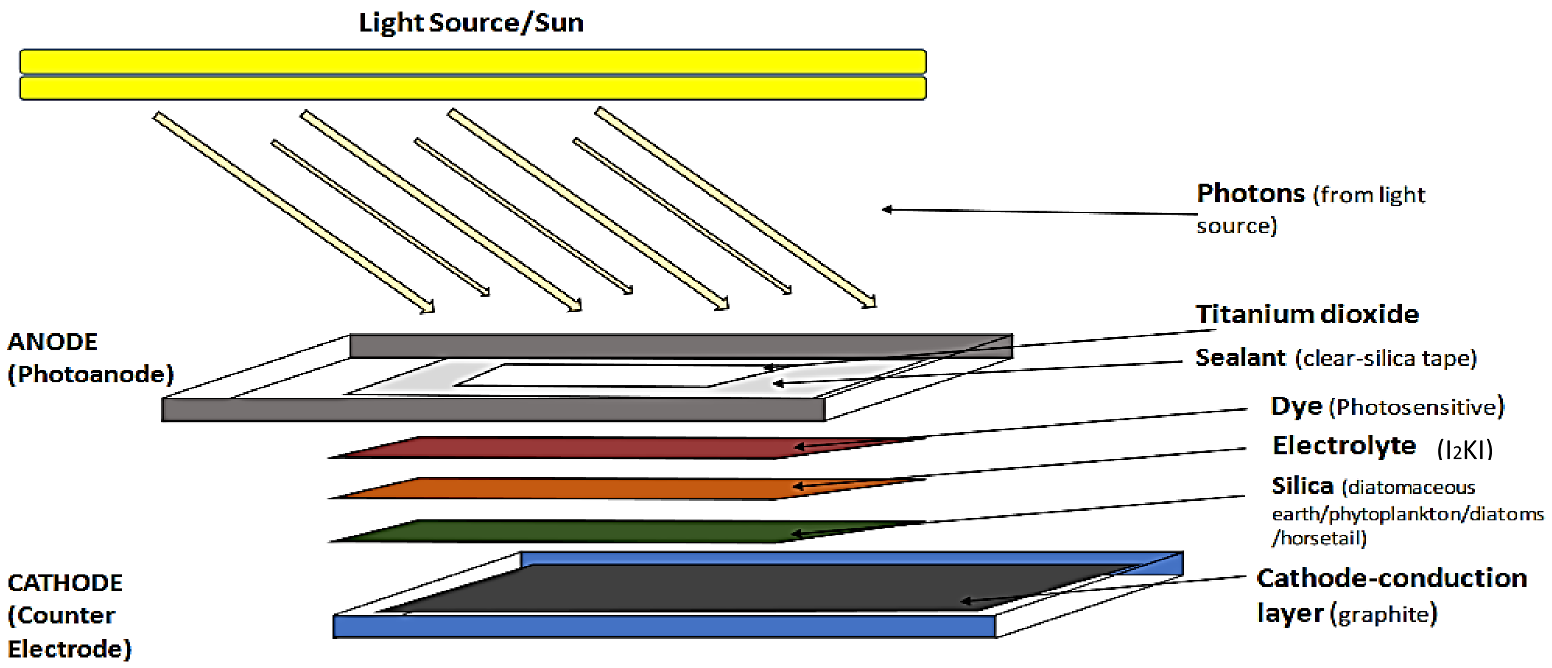


Figure 5. Diagrammatic representation of a DSSC with orientation of parts inside.

Titanium Dioxide

Titanium dioxide (TiO_2) is white and has the capability to absorb dyes and other photosensitizers. Since the DSSC's inception, TiO_2 has been the research standard for its wide band gap and porous nature (Su'ait et al., 2015). Commercially, TiO_2 is a very light, white powder, as seen in Figure 6. A paste was made using 18 g of TiO_2 powder and diluted acetic acid (1:50) in water, at a pH between 3.5 – 3.8. Preparation of the paste was done in the hood to prevent inhalation of the fine powder. TiO_2 was ground in a crucible with a pestle to compress the powder. 1-2 mL was added in 2-minute intervals until the powder-paste is uniform. Roughly 12-13 mL of the acetic acid solution was used within a time span of 30 minutes. The paste was moved to a capped glass vial and stored in the refrigerator until the next step. Lifespan of the paste is dependent on how well sealed the storage is from exposure. TiO_2 paste can be stored in the refrigerator for weeks until the paste dries past a spreadable texture. To correct for dry texture if the paste is not too dry, the acetic acid solution may be added in 0.5 – 1 mL increments until the desired texture is present. To aid in texture for spreading, two drops of surfactant, Triton 100X, was added without mixing or agitation. TiO_2 will only be added to the anode side, where it will connect with the cation once closed.

Figure 6. Titanium dioxide before mixed into paste.

Glass Cells

The integrity of the cell relies on the symmetry of the glass components. The center zone where the working electrode works is where the space between is minimized, and the surface area contact is at its greatest to all components. As mentioned previously these glass cells are pre-coated with Tin (Sn) on one side to aid in conducting the electricity and energy create and cycled following light absorption. This substrate allows TiO_2 to adhere well and other molecules that facilitate electron transport and motility. The other side of the glass is used to function as the counter electrode. One can use a voltmeter to determine which side is the conductive side, the Sn-doped side. Glass cells are cleaned with soap, water, and ethanol before use. The two halves are represented in Figure 7.

Glass slides are either the cathode or anode half based on the method of preparation. Constructing a cathode involved taking a graphite pencil and coating the surface till the surface is evenly coated. The anode cells are taped to the table with Sn-coated side up. The tape was placed over with an open square in the middle to allow for paste to be placed. Binding of the TiO_2 paste is sometimes inconsistent, so a small drop of surfactant is added and spread across the exposed portion, then wiped away with lens paper. TiO_2 paste is dabbed onto the cells with a stirring rod, then spread with either are razor or a glass slide, shown in Figure 8. This method is also known as the “doctor blade method” as to describe the use of a single-use razor or blade to spread the layer as thin as possible. Tape was placed to make a 1mm x 1mm square for the paste. Thickness was crucial as to provide a proper surface for a dye, electrolyte, and silica resource to interact and conduct electricity. Drying and cracking occurred if the plate wasn't immediately moved to a Bunsen-burner to anneal.

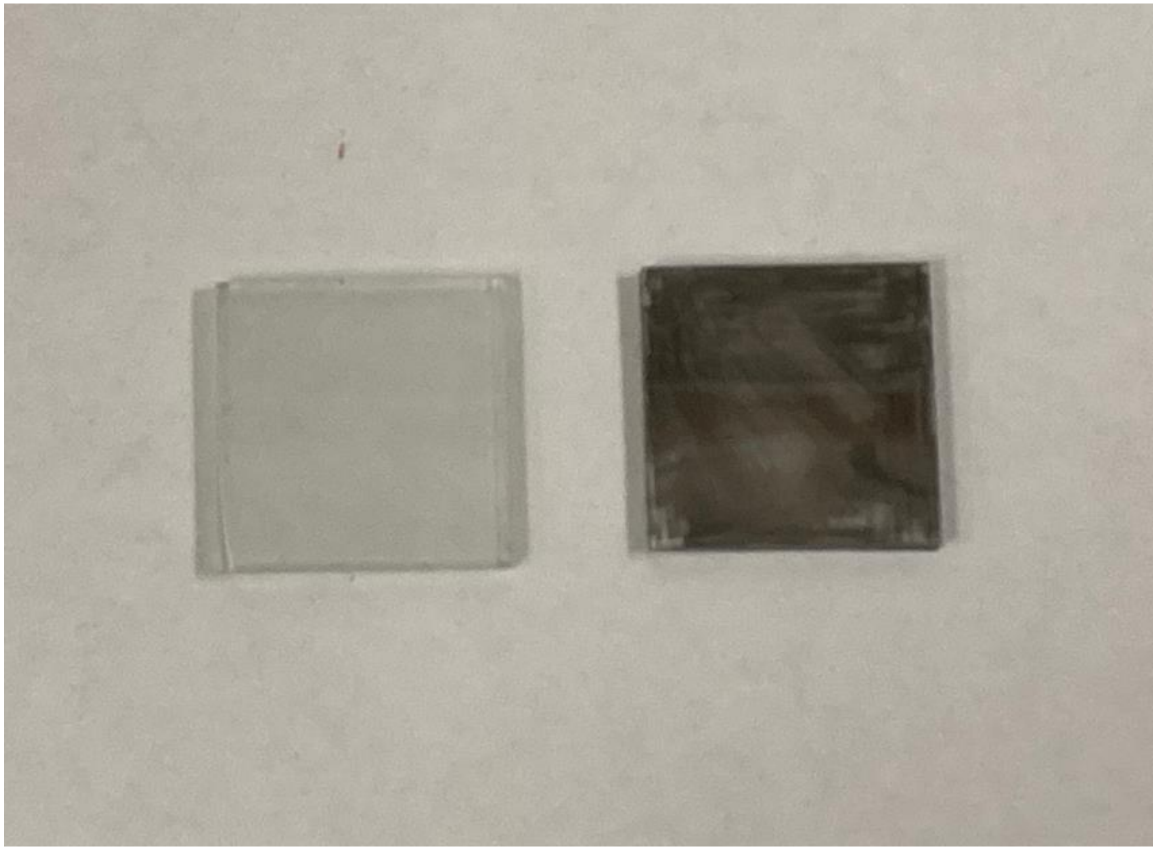


Figure 7. Anode slide (left) and cathode slide (right) before treatment and attachment.

Figure 8. Cell prepared for the doctor blade method of spreading titanium dioxide paste.

When the cells anneal the heat burns off miscellaneous products in the paint as it melts and adheres to the glass plate. Annealing temperatures differ among the materials heated and what surface taken place. Its estimated that the Bunsen burner is reaching to temperatures of 500 ºF. Annealing took 4 - 5 minutes, though color changes to the paint was the major indicator of completion. TiO_2 undergoes color changes during heating when chemical by-products are made through combustion and released. Once burn off is finished, paste returns to its former white coloration. Plates are moved off the flame to a nearby rack to cool, as the glass is still extremely hot and still sensitive to cracking. This method is still known to potentially crack some plates, though only seven plates were lost to overheating or pre-existing cracks. The surface is known also to show cracking of the TiO_2, which can still be used if it does fall off to air. A final integrity test was used by waving a notebook over the cells to determine if they have annealed properly. A rule in construction was if 80% of the TiO_2 working electrode surface remained then the cell was salvageable for research. This saved time and resources as to not waste any paste. Once annealed these cells can last for months until the integration a dye and silica materials. After several preliminary attempts, this method has been evaluated multiple times and has been most effective in efforts to acquire a stabile working electrode for these cells.

Dye

The dye is an essential piece of the completed DSSC model, where it facilitates the excitement and absorption of photons from a light source. Just as organisms have optimized absorbent photosensitizers or pigments, dyes have been selected and constructed to maximize interactions with the working electrode. Sharma et. al (2018) found that throughout most research projects managing a DSSC model, dyes that are at the nearultraviolet spectrum or near-infrared had their highest efficiency charges. Dyes interaction with photons to transfer electrons is aided by the directionality of flow from cation and anion interactions and are replenished by the rejuvenated electrons from the prior redox from iodine/triiodide reactions. Solubility of the of the dye is crucial for the sake of ensuring components do not interfere with integration into the central matrix.

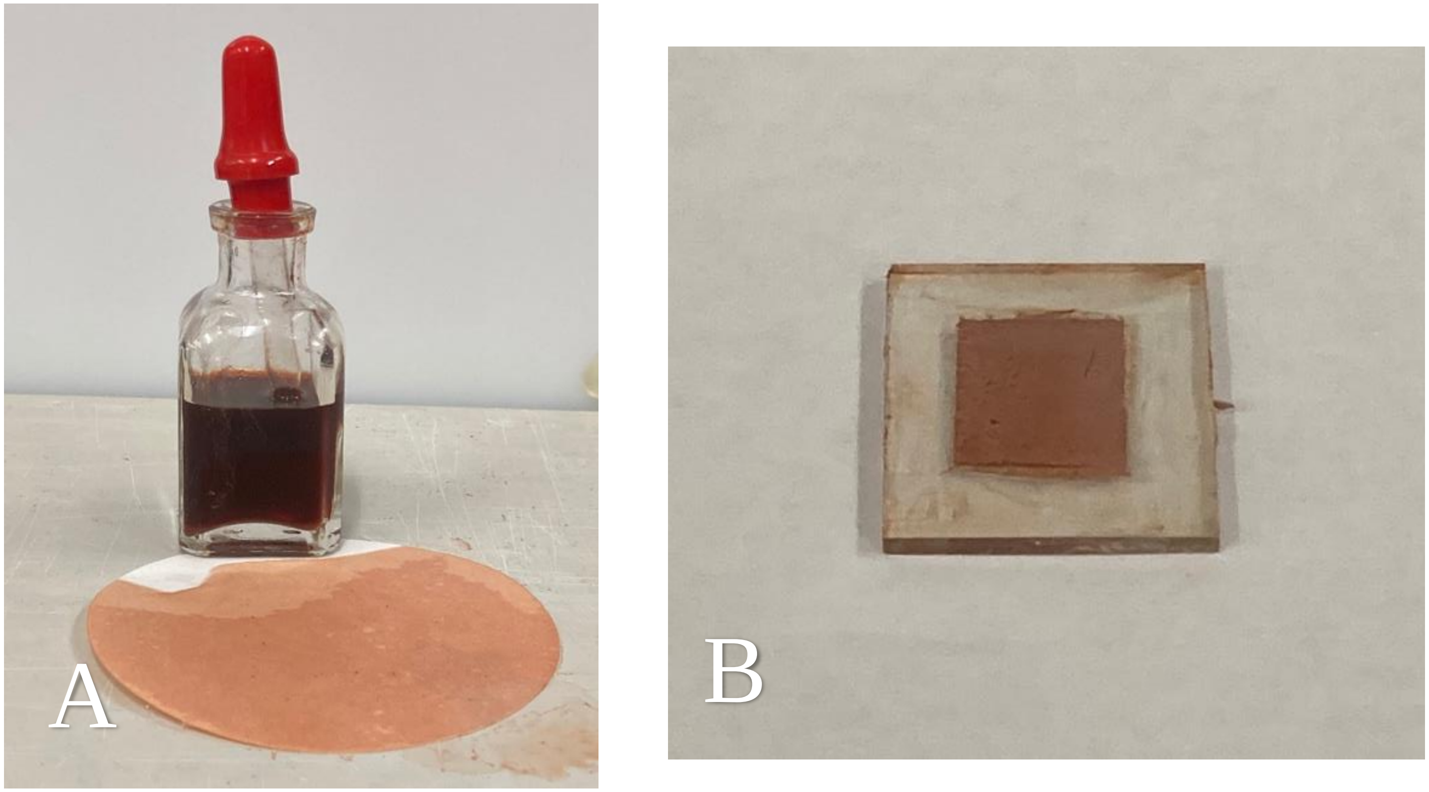
Dragon’s blood dye was made using ingredients from a prior study from Jones and Bidlack (2015) to discover eco-friendly and potentially durable dyes, instead of expensive and toxic synthetic pigments. Dragon’s blood dye is processed from *Daemonrops draco* Blume resin in a package purchased online from Red Earth, on the Amazon online marketplace. Use of this as the dye was based on its effectiveness with prior treatments, and to observe further results for future suggestions. Resin was ground in a crucible to a fine powder for highest yield of dye. In a 50mL container 20 g of resin was added followed by 30 mL of 80% ethanol/ 20% acetone. The container was sealed with a cap and shaken for several minutes to suspend the particles for better immersion, then stored in the refrigerator until everything has settled, approximately two hours after shaking. The supernatant will be the dye used to coat the TiO_2 squares before the other components are added. Extracted dye is best kept in cool temperatures and out of excess exposure to light, if possible, so to avoid potential denaturing of the dye. Refer to Figure 9a and 9b for its robust, red color. The lifespan of most dyes can be several years if kept in proper conditions. Cells used for dye-integration received 200 µL of Dragon’s blood dye and left to dry for 2 hours. If not all the TiO_2 is covered, another 100uL is added to cover such spots. The resin dye can leave a residue on the edges of the glass that is non-harmful to the cell, but may have attribute to issues with adhesives used, thus all edges of the cells are cleaned with ethanol. Cells used for dye-integration received 200 μL of dragon's blood dye and left to dry for two hours. If not all the TiO_2 is covered, another 100uL is added to cover such spots. The resin dye can leave a residue on the edges of the glass that is non-harmful to the cell, but may have attribute to issues with adhesives used, thus all edges of the cells are cleaned with ethanol. Four treatment groups received staining with one group left un-stained as a control. It was important to note that both the horsetail treatment and phytoplankton treatment carry themselves various chlorophyllins and carotenoids, all which can absorb light and transform such incidence into energy.

Treatments

Five treatments were made for this study, each with four cells for each repetition. Treatments included ground *Equisetum hyemale*, diatomaceous earth (DE), phytoplankton culture, untreated, dye impregnated cell, and a no-dye control cell (Figure 10). These treatment groups allowed for an analysis of potential influences between groups with, without, or with both silica and chlorophyllin.

Horsetail

Equisetum was purchased online through Amazon's distribution website, from Sugarman Candy, pre-dried and pre-cut. A bio-emulsifier was used to cut the horsetail into a fine powder (Figure 13). This process was repeated five times, along with cleaning out any larger pieces that did not completely reduce (Figure 14). Cells utilizing this treatment received 75 mg that was placed with a spatula into the center space.



Figures 9A and 9B: (A) Dragon's blood dye in a dropper bottle and filter disc to show color; (B) solar cell with dye absorbed.

Diatomaceous earth

Diatomaceous earth (DE) was purchased online through Amazon's distribution website, from Absorbent Products Inc. As to not alter the substance, untreated DE was purposefully purchased to not alter or deteriorate the cell. Cells in this group received 75 mg, filling the center zone via spatula. Figure 11 shows the coloration and form of the DE used in this experiment.

Phytoplankton

Phytoplankton solution was made by Brightwell Aquatics and purchased through Amazon. The solution contained a mixture of species from the genus, *Tetraselmis,* a unicellular alga. Each cell with this treatment received 350 µL of solution, an amount that would fill the center without spill. Solution was allowed to settle before extraction to ensure phytoplankton could be collected and transferred. Figure 12 provides what the solution appears as from the bottle.

Controls

Treatments outside of the controls focus on a physical and chemical alteration that may influence how the cell may perform in voltage. Two control groups were added to represent effects with a dye and without it to set a floor for cells without proper components. This group provided a bridge to understand the dye’s influence and potentially relate it to other groups with manipulated centers.

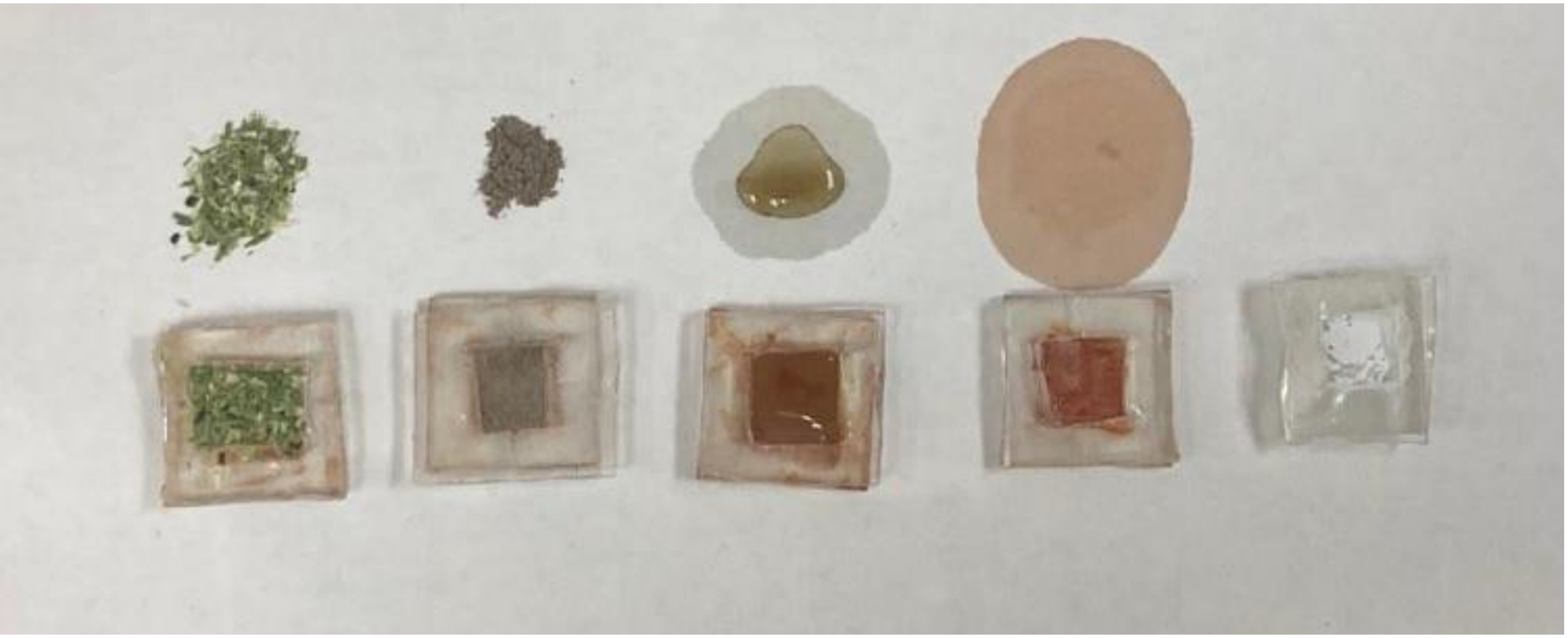
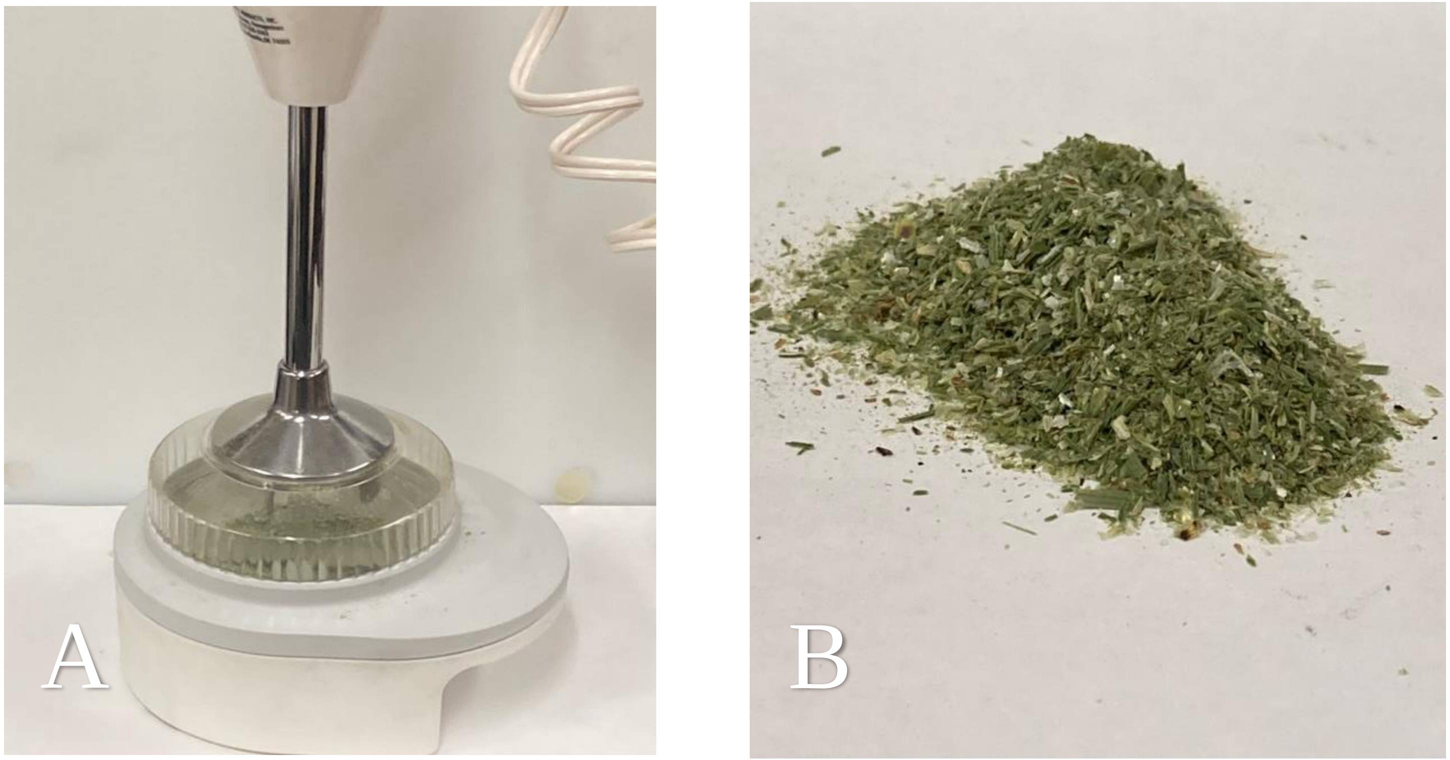


Figure 10. An array of cells with various treatments in the cell, with a tape sealant to hold materials within. From left to right: *Equisetum* (horsetail), diatomaceous earth, phytoplankton solution, dye-only, and no dye control.



Figures 11A and 11B. (A) Horsetail in the bio-emulsifier; (B) ground horsetail (*Equisetum spp*.).

Figure 12. Diatomaceous earth before placed into the central zone.

Figure 13. Phytoplankton solution on a piece of paper to show color and form.

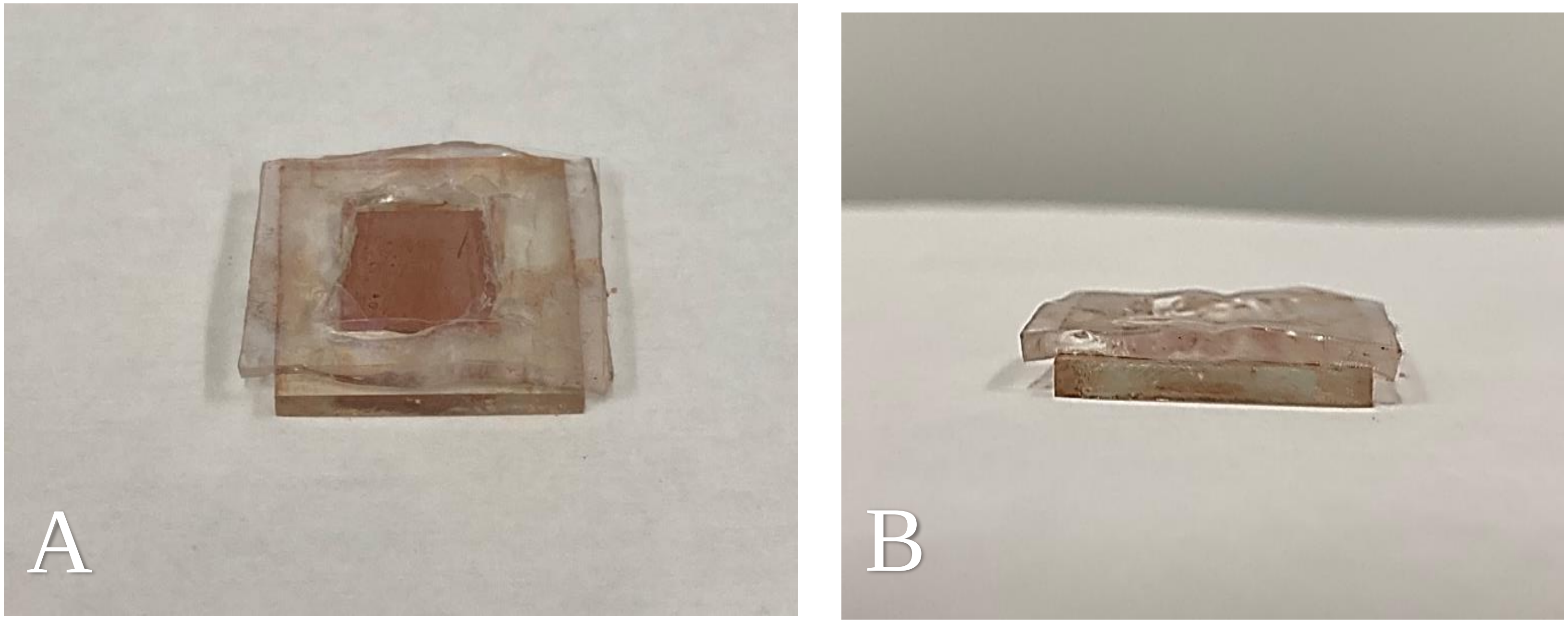
Electrolyte

Electrons in the cell cannot be shared or retuned to state without the aid of an electrolyte that can enable the replenishing of dye-state electrons. Potassium triiodide (I_2KI) has been the electrolyte in the treatments as a stable and somewhat safer chemical to use for the purpose of solar cells. This electrolyte has a less toxic affinity compared to other known electrolytes and thus can help with affordability and eco-conscious safety. I_2KI can be purchased online through various aggregates and was purchased from Sigma Aldrich.

Potassium triiodide was stored in a dropper bottle and kept in a dark location to prevent denaturing the solution. Applying the electrolyte with minimum leaking was with a minimal puncture using a syringe through the bottom of the cell after adhering both ends together. Each cell received 350 µm, which was measured to not obstruct the additive contents. Cells that leaked before attachment were cleaned but not retreated as to not fluctuate the values.

Sealing

Binding the glass parts together requires tools that can hold the components while not leaking liquid components. Silicon tape has proven to be a successful tool to connect both the anode and cathode together, while also providing a small area where the TiO_2, graphite, electrolyte, dye, silica additions, and light can interact. Though the tape was resilient once placed, the electrolyte and planktonic solution could have found ways to spill out of the cell once clamped close though the seal provides some room. Figures 14A and 14B represent different angles of the seal.



Figures 14A and 14B: (A) View from above of cell with cut and measured adhesive strip; (B) Side view of cell with adhesive strip.

A non-toxic silicon adhesive was added to the surrounding edges where leaks may be possible. A strategy to clamp both ends both with normal black binder clips, as done in the Bidlack Research lab via FitzSimmons (2007) and Jones (2015), provided sufficient closure of the core and glass halves. These devices could be placed at ends that would not disrupt the integrity of the cell, nor its ability to connect to meters for measurements. The cells were left to sit for an hour to allow the gel to finish setting.

Lighting and Temperature Control

Exposure to light and recording took place in an environmental chamber (Figure 16). This chamber can cycle through intervals of light exposure that simulates day and night interactions. Temperature in the chamber can be controlled with the help of fans connected to the top level where it operates through a vent on the inner ceiling. Cells were connected on a rig that was made many years ago for this and prior solar research. The rig consists of two rows on opposite side with 7-8 clips that attach to both the cathode and anode of the cell (Figure 17). Each clip has a wire that connects to a main hub (PICO-connector), where information is fed to the computer to record voltage from the solar cell. Four rigs with seven slots are used with a maximum capacity of 28 cells to be recorded. Spacing can be critical in the setup of the cells on the rig as shifting can occur when cells begin to dry and fail. Four lanes ran simultaneously, each with five different treatment groups. A randomized complete block design distributed treatments without bias. PicoScope software installed onto a computer inside the chamber recorded data points in various intervals. One-hour intervals were chosen to identify changing trends in a day and between days. After 10 days, cells are removed and data is saved for SAS analysis.

Measurements

Recorded values reflected where a cell maximized on energy output (mV) and how it changed over time (t). Cells were recorded for 10-day intervals to ensure future cell setup and turnover was possible, in the event of the school being or if the chamber lost power during building construction. PicoScope software recorded real-time measurements for voltage values over time. Figures 18a and 18b demonstrate the software data during and after recording. At the end of each run, the program reorganizes the values displays both a spreadsheet and graph copy to evaluate visual trends.

Four racks hold one cell per treatment group: phytoplankton, diatomaceous earth, ground horsetail, dye control, and no dye control. Statistical analysis of the data includes a line graph that shows how the cells performed through the cyclic-light cycles. As mentioned previously, the chamber is programmed to simulate day and night cycles by turning off at 8 pm. Once a cycle is complete, a spreadsheet is provided by the software that organizes readings per hour for each channel recording. As mentioned prior, this project's intent is a focus on capable materials and exploration of avenues before resistance and current will be taken into consideration.

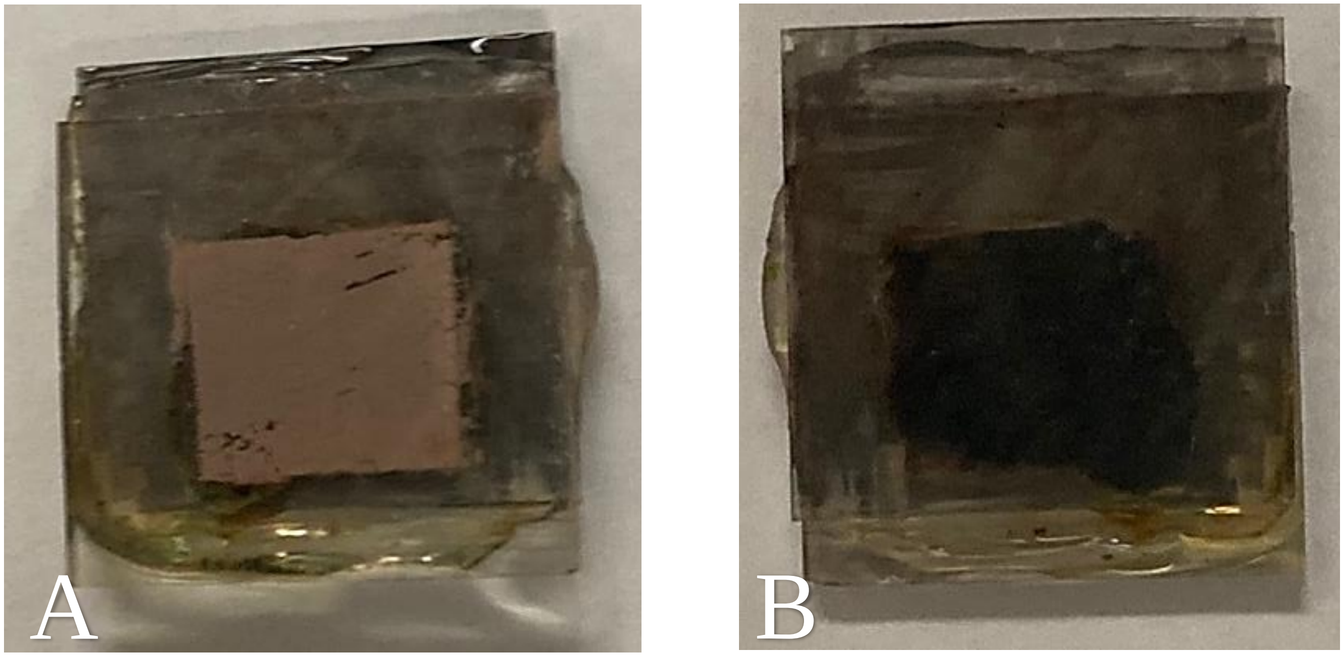


Figure 15A and 15B: Solar cell connected with both cathode and anode. This cell has the horsetail treatment incorporated.

Viewpoints: (A) anode and (B) cathode

Figure 16: Environmental chamber located at the University of Central Oklahoma.

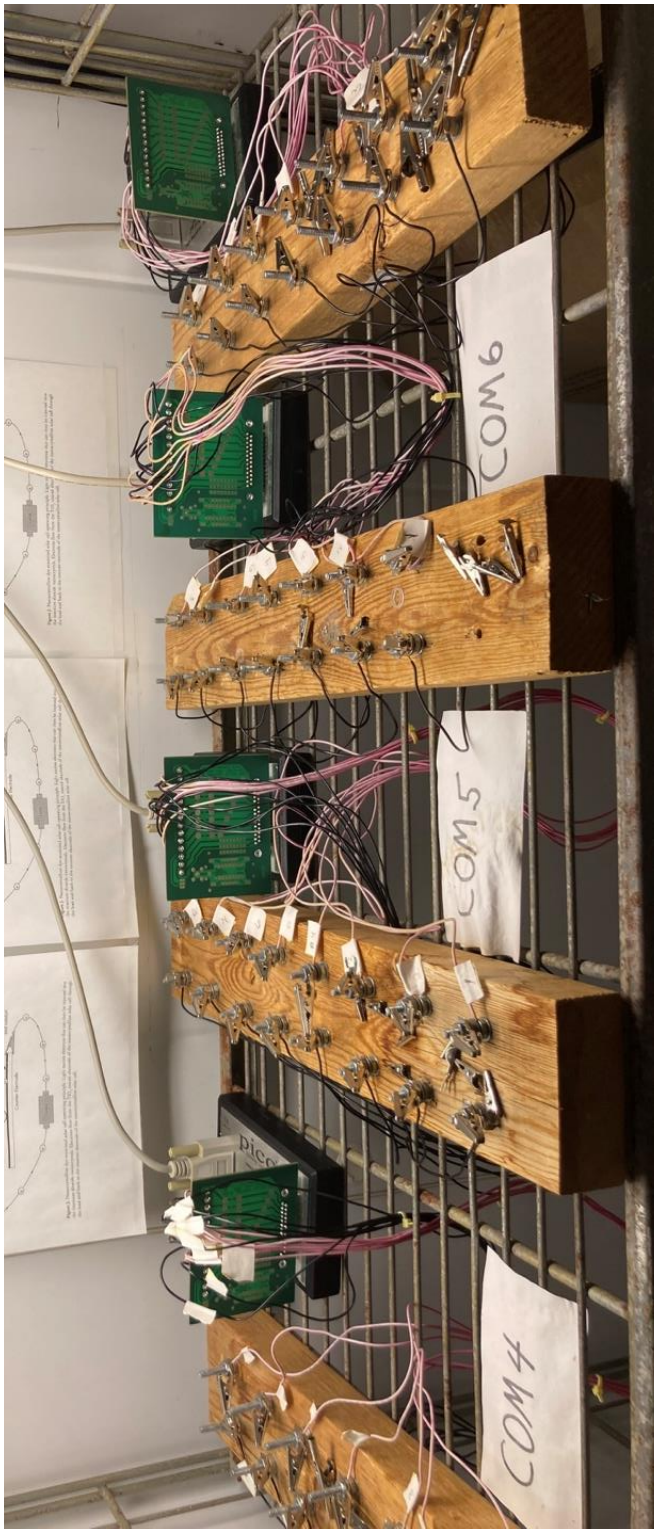
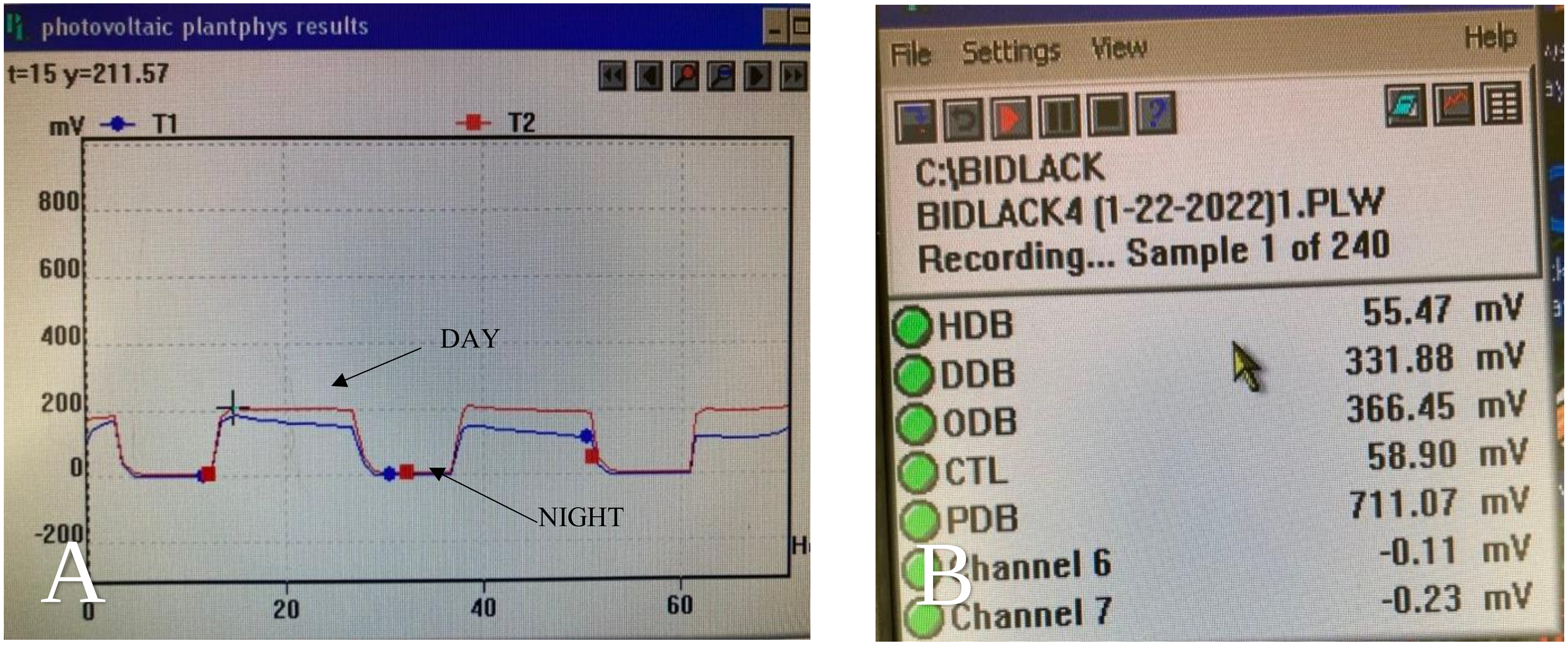


Figure 17: Racks specialized for work with DSSCs. Each rack is connected to a PICO-connector and reads up to eight cells at once.



C:\BIDLACK
BIDLACK4 (1-22-2022)1.PLW
Recording... Sample 1 of 240

HDB	55.47 mV
DDB	331.88 mV
ODB	366.45 mV
CTL	58.90 mV
PDB	711.07 mV
Channel 6	-0.11 mV
Channel 7	-0.23 mV

Figures 18A and 18B. (A) PICO-connector system that can record voltage of DSSCs. (B) Picture of PICO-connector system with corresponding treatment groups: HDB (Horsetail), DDB (DE), ODB (Only-dye), CTL (Control), and PDB (Phytoplankton)

RESULTS

Statistics

Statistics were conducted using SAS software executed on the X64_7PRO platform. Input variables included trial, repetition, treatment, light, day, and voltage. 1,140 data points were used for the final analysis (600 = Day, 540 = Night). Primary data points were removed to have all trial start at 8:00 am, explaining why less data points exist for this variable. Means of overall values for repetitions were calculated with both separate and complete analysis and variance (ANOVA) for all data. A general linear model (GLM) procedure best utilized these data to evaluate statistical differences amongst various variable to voltage values. Data for overall, day, and night values were collected for interpretation using general linear models (GLM) and ANOVA to evaluate not only differences in treatments, but also in time intervals to show if cells showed significant shifts that warrant discussion.

With voltage as the dependent variable for GLM, treatment types appeared to suggest a significant effect ($F = 92.36$; $p < 0.0001$) on the response variable, voltage. Day and night variables, designated as "light," also showed differences against voltage ($F = 287.43$; $p < 0.0001$). Day by day variation also appeared to influence the model ($F=37.39$; $p < 0.0001$). Data also confirmed that trails alone as a variable against voltage response failed to reject the null hypothesis of no influence ($F = 2.06$; $p = 0.1275$; $\alpha \leq 0.05$), and suggested no differences among each run, as well as the relationship in the function of trial*day to voltage ($F = 0.0639$; $p = 0.0639$; $\alpha \leq 0.05$). The function of light*treatment*day's relationship to voltage suggested that significant differences were present and suggest that such function also warrants investigation ($F = 1.73$; $p = 0.0078$; $\alpha \leq 0.05$). These values are given based off type III sum of squares analysis to confirm if values shifted to significance from none.

GLM involves conducting F-tests for voltage to evaluate once again how various other variables are affected with the model and determine whether one variable acts upon another. Alpha was 0.05 along with a critical value of F at 1.96277 (LSD = 8.4011). All trials remained within range to maintain that experimentation did not show significant differences amongst separate attempts. F-grouping with SAS utilizes a letter system that test values if they are not exceeding the bounds of the LSD threshold. Table 1 shows how the trials compared to each other via LSDs.

Trials

Runs, labeled "trials," were compared with each other to evaluate potential differences or similarities between different runs. This data helps ensure that no issues will be present when conducting comparisons between the three trials. Figure 19 represents the box plot model of each of the three trials. Tables 1 and 2 provide a means to use overall averages of trials to compare how close means were from significance of difference.

Day and Night

Analysis involved looking at the potential effects between day/night represented as, “light," to voltage. Differences in means suggested a difference between day and night periods of collection, represented in the tables 3 and 4, and in Figure 20 as a box plot.

Treatments

Groups were analyzed for differences between other treatments through voltage averages. Values to determine significance included looking at least significant differences among other treatments. Tables 5 and 6 below detail the results of analyses via a letter-grouping system. Figure 21 is a box plot of average means of voltage including both day and night values for each treatment type (n=228).

Day to Day Intervals

To establish a comparison between different days of the trails, a t-test for LSD values in voltage was conducted, using $\alpha \leq 0.05$. Day to day comparisons used difference between means (DBM) to analyze the values lying within a 95 % confidence limit. If a limit range has “0” within it, the comparison does not warrant rejection of the null at that point. Tables 7a-d represent how values were presented and at what intervals reject the null and confirm a significant change between two points of time. Rows with "+" are intervals with relative significance in voltage change.

Day vs. Night

Day and nighttime periods were separately analyzed following a total review to evaluate potential happenings and stabilities for both. As mentioned prior, a full night cycle was omitted as thus leaving "night" with less observations (n=540) as compared to day values (n=600). For these two groups, GLM and separate ANOVAs calculated potential effects that may carry significant weight for their role in the model's alterations and treatments.

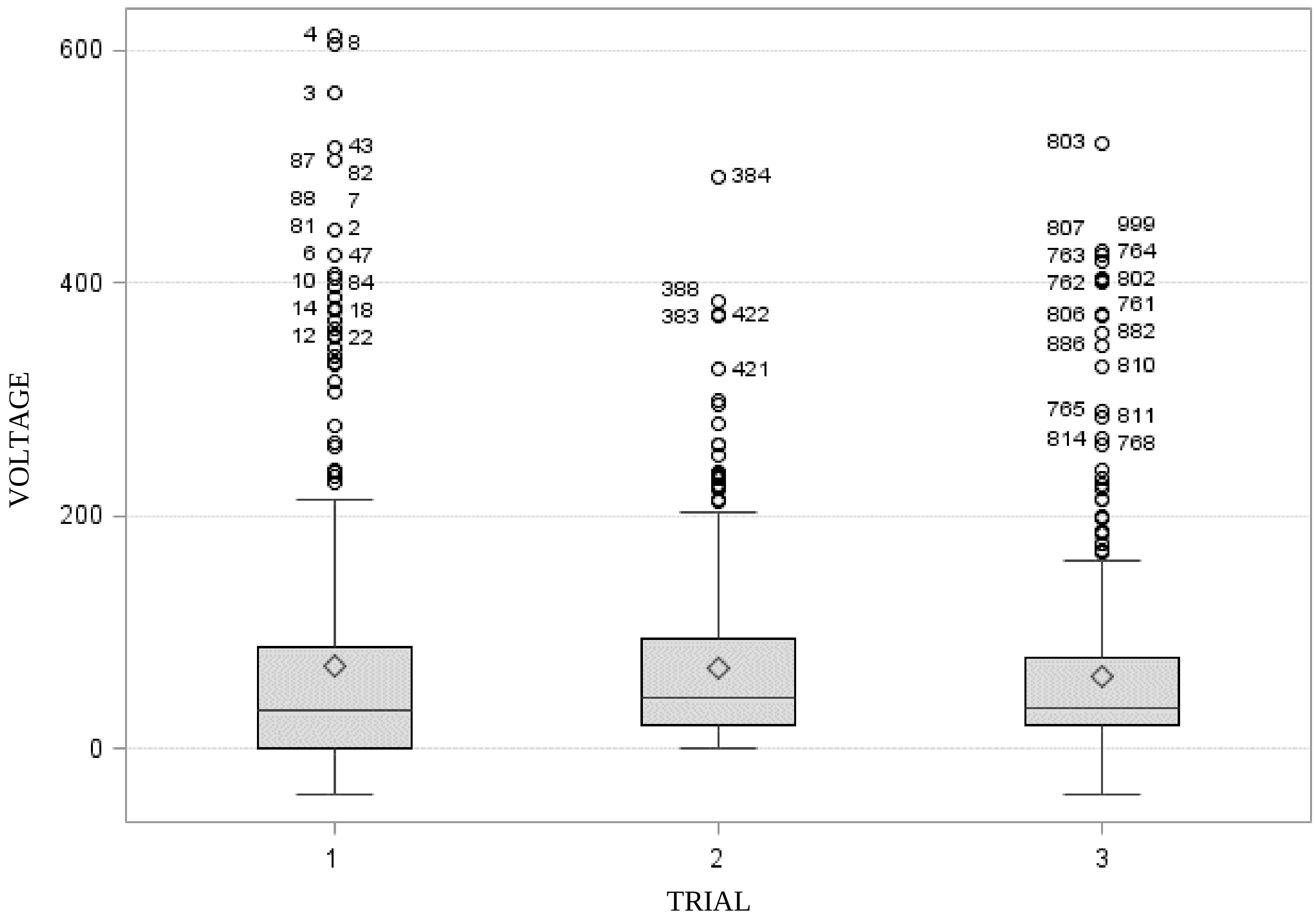


Figure 19. Distribution of overall voltage values from all three trials. Box plots indicate a least mean squares area that represents most likely values within 95% confidence, along with standard deviation.

Table 1. Table of values for evaluating F-test values using means, comparing trials.

Alpha	0.05
Error-Degrees of Freedom	846
Error Means Square	3480
Critical Value of F	1.962
Least Significant Difference	8.401

Table 2. F-tests with least significant difference values of voltage for grouping by trial.

LSD grouping via means per trial			
Groups	**Mean (mV)**	**n**	**Trial**
A	70.30	380	1
A			
A	68.95	380	2
A			
A	62.18	380	3

Legend: Letters define grouping, where different letters show difference from trials if any.

Table 3. Table of values for evaluating means via F-tests, comparing day and night.

Alpha	0.05
Error Degrees of Freedom	846
Error Mean Square	3480
Critical Value of F	1.96
Least Significant Difference	6.87
Harmonic Mean of Cell Sizes	568

Table 4. F-tests with least significant difference voltage means, grouping by time of day.

LSD grouping via means per trial			
Groups	**Mean (mV)**	**n**	**Light**
A	95.2	600	Day (D)
B	35.9	540	Night (N)

Legend: Means with the same letter are not significantly different.

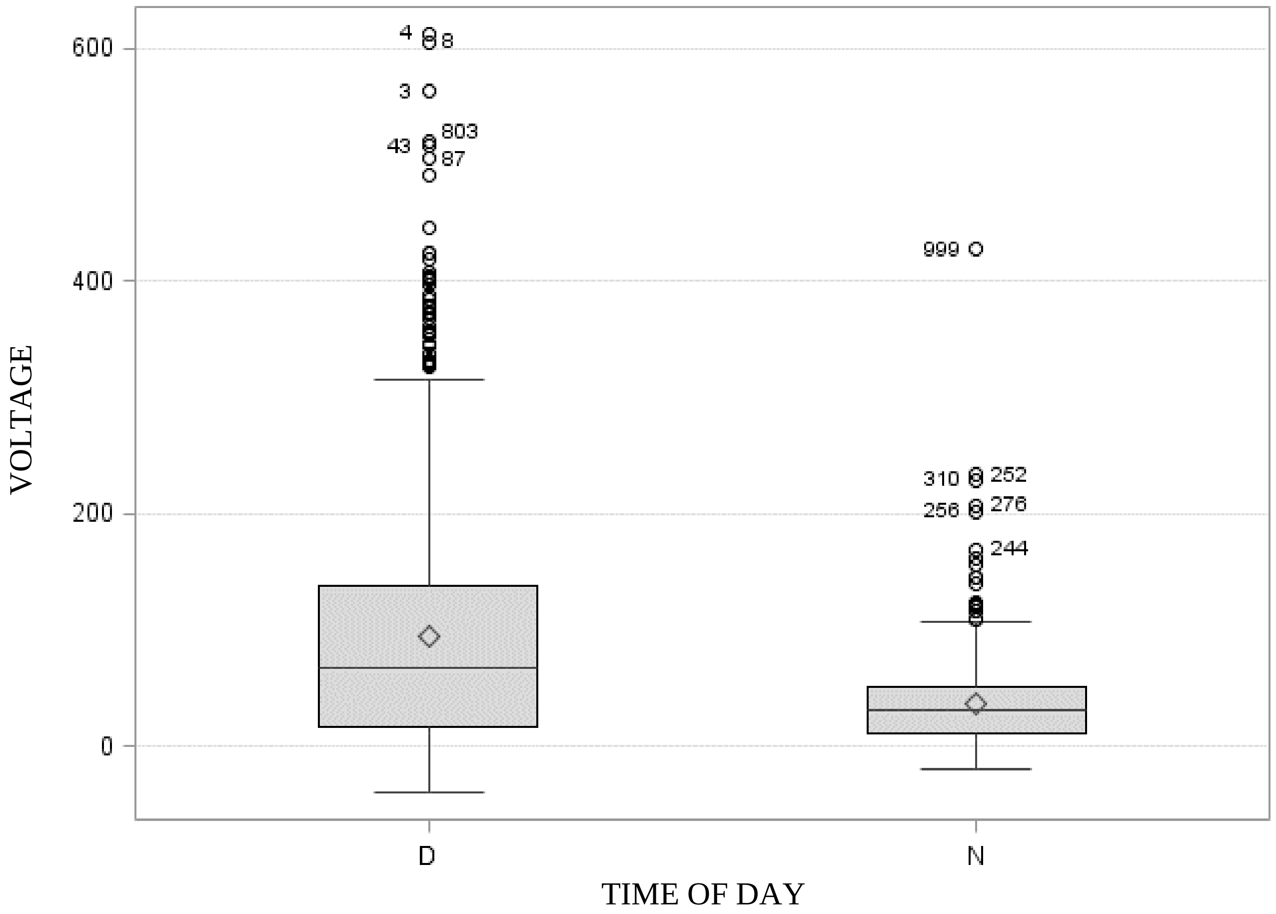


Figure 20. Distribution of voltage values separated by day (D) and night (N), along with standard deviation.

Table 5. Table of values for evaluating means via F-tests, comparing treatments.

Alpha	0.05
Error-Degrees of Freedom	846
Error Means Square	3480
Critical Value of F	1.96
Least Significant Difference	10.8

Table 6. F-tests with least significant difference voltage means, grouped by treatments.

LSD grouping via means per treatment group			
Groups	**Mean**	**n**	**Treatment**
A	106	228	HDB (*Equisetum* spp.)
A	97.2	228	DDB (Diatomaceous earth
B	72.8	228	PDB (Phytoplankton)
C	44.2	228	ODB (Only-dye)
D	15.5	228	CTL (No-dye/Full Control)

Legend: Means with the same letter are not significantly different.

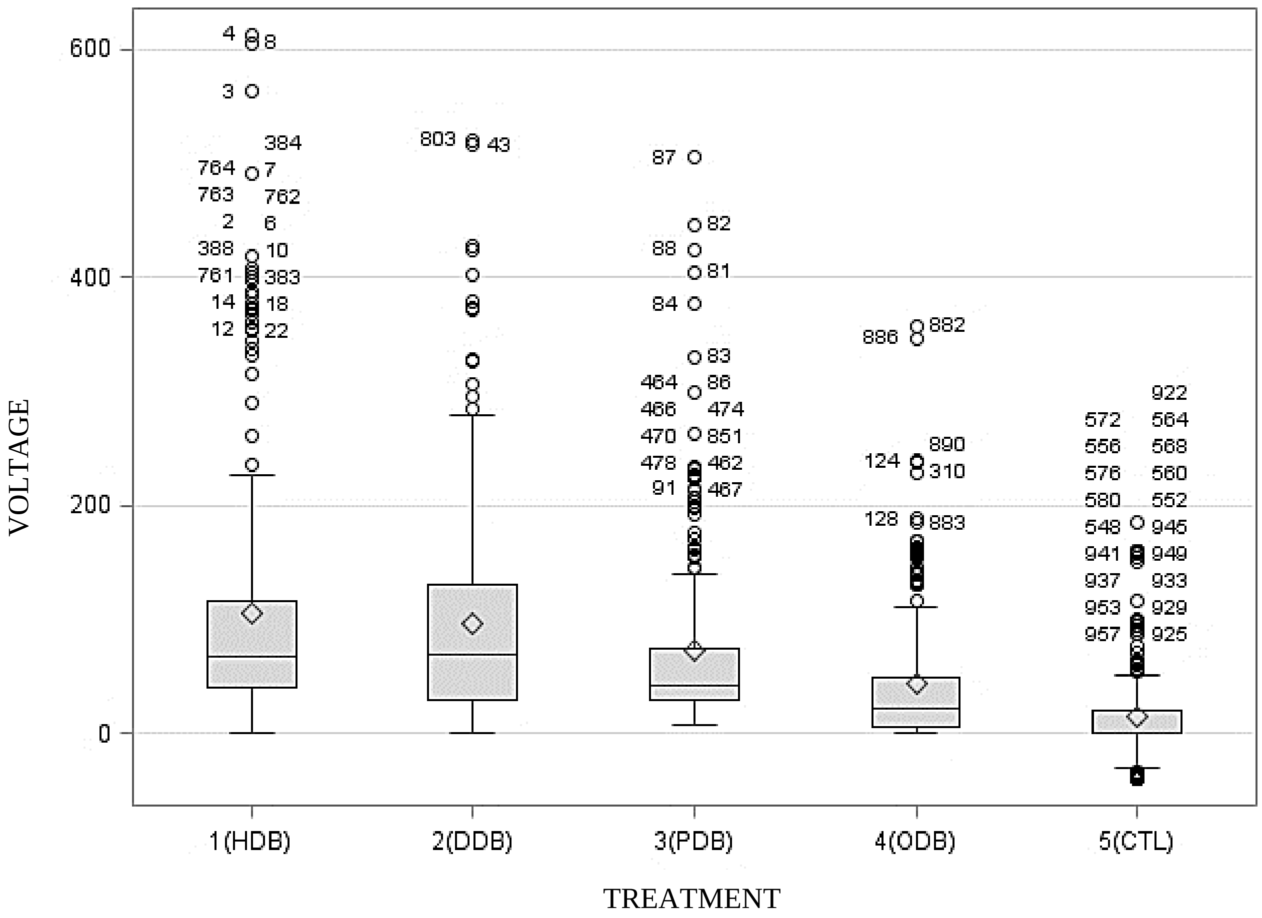


Figure 21. Distribution of voltage as a value to different treatment groups. Vertical bars designate standard deviation. Groups left to right: Horsetail (HDB), Diatomaceous earth (DDB), phytoplankton (PDB), only-dye control (ODB), and no-dye control (CTL).

Table 7A. Comparisons of means to determine variance and significance between different days in intervals.

Comparisons between time intervals for all treatments				
Day Comparison	**Difference Between Means**	**95% Confidence Limits**		**Significance (+/-)**
1 - 2	24.2	9.21	39.1	+
1 - 3	51.8	36.9	66.8	+
1 - 4	69.2	54.3	84.2	+
1 - 5	76.7	61.8	91.7	+
1 - 6	82.7	67.7	97.7	+
1 - 7	88.7	73.8	103.7	+
1 - 8	92.7	77.7	107.6	+
1 - 9	95.3	80.3	110.2	+
1 – 10*	81.6	63.3	99.9	+
2 - 1	-24.2	-39.1	-9.20	+
2 - 3	27.7	12.7	42.6	+
2 - 4	45.1	30.1	60.03	+
2 - 5	52.6	37.7	67.6	+
2 - 6	58.5	43.6	73.5	+
2 - 7	64.6	49.6	79.5	+
2 - 8	68.5	53.6	83.5	+
2 - 9	71.1	56.2	86.1	+
2 – 10*	57.4	39.1	75.8	+
3 - 1	-51.8	-66.8	-36.9	+
3 - 2	-27.6	-42.6	-12.7	+
3 - 4	17.4	2.47	32.4	+
3 - 5	24.9	10.01	39.9	+
3 - 6	30.9	15.9	45.8	+

Legend: Values with ranges that include "-" as a value are not significant in such intervals. “*” on the chart indicates a day that only accounts for last day cycle.

Table 7B. Continuing comparisons of means to determine variance and significance between different days in intervals.

Comparisons between time intervals for all treatments

Day Comparison	**Difference Between Means**	**95% Confidence Limits**		**Significance (+/-)**
3 - 7	36.9	21.9	51.8	+
3 - 8	40.9	25.9	55.8	+
3 - 9	43.5	28.5	58.4	+
3 – 10*	29.8	11.5	48.1	+
4 - 1	-69.2	-84.2	-54.3	+
4 - 2	-45.1	-60.03	-30.1	+
4 - 3	-17.4	-32.4	-2.48	+
4 - 5	7.53	-7.42	22.5	-
4 - 6	12.4	-1.49	28.4	-
4 - 7	19.5	4.52	34.4	+
4 - 8	23.4	8.49	38.4	+
4 - 9	26.03	11.09	41.0	+
4 – 10*	12.4	-5.94	30.7	-
5 - 1	-76.8	-91.7	-61.8	+
5 - 2	-52.6	-67.6	-37.7	+
5 - 3	-24.9	-39.9	-10.01	+
5 - 4	-7.53	-22.5	7.42	-
5 - 6	5.93	-9.02	20.9	-
5 - 7	11.9	-3.009	26.9	-
5 - 8	15.9	0.951	30.8	+
5 - 9	18.5	3.55	33.4	+
5 – 10*	4.83	-13.4	23.1	-
6 - 1	-82.7	-97.7	-67.8	+

Legend: Values with ranges that include "-" as a value are not significant in such intervals. “*” on the chart indicates a day that only accounts for last day cycle.

Table 7C. Continued comparisons of means to determine variance and significance between different days in intervals

Comparisons between time intervals for all treatments				
Day Comparison	**Difference Between Means**	**95% Confidence Limits**		**Significance (+/-)**
6 - 2	-58.5	-73.5	-43.6	+
6 - 3	-30.9	-45.8	-15.9	+
6 - 4	-13.6	-28.4	1.49	-
6 - 5	-5.93	-20.9	9.02	-
6 - 7	6.01	-8.94	20.9	-
6 - 8	9.97	-4.98	24.9	-
6 - 9	12.6	-2.37	27.5	-
6 – 10*	-1.096	-19.4	17.2	-
7 - 1	-88.7	-104.0	-73.8	+
7 - 2	-64.6	-79.5	-49.6	+
7 - 3	-36.9	-51.9	-21.9	+
7 - 4	-19.5	-34.4	-4.52	+
7 - 5	-11.9	-26.9	3.01	-
7 - 6	-6.011	-20.9	8.94	-
7 - 8	3.96	-10.9	18.9	-
7 - 9	6.56	-8.39	21.5	-
7 – 10*	-7.11	-25.4	11.2	-
8 - 1	-92.7	-107.4	-77.7	+
8 - 2	-68.5	-83.5	-53.5	+
8 - 3	-40.9	-55.8	-25.9	+
8 - 4	-23.4	-38.4	-8.49	+
8 - 5	-15.9	-30.9	-0.951	+
8 - 6	-9.97	-24.9	4.98	-

Legend: Values with ranges that include "-" as a value are not significant in such intervals. “*” on the chart indicates a day that only accounts for last day cycle.

Table 7D. Continued comparisons of means to determine variance and significance between different days in intervals

Comparisons between time intervals for all treatments				
Day Comparison	**Difference Between Means**	**95% Confidence Limits**		**Significance (+/-)**
8 - 7	-3.96	-18.9	11.0	-
8 - 9	2.60	-12.3	17.5	-
8 – 10*	-11.07	-29.4	7.24	-
9 - 1	-95.3	-110	-80.3	+
9 - 2	-71.1	-86.1	-56.2	+
9 - 3	-43.5	-58.4	-28.5	+
9 - 4	-26.0	-40.9	-11.1	+
9 - 5	-18.5	-33.5	-3.55	+
9 - 6	-12.6	-27.5	2.37	-
9 - 7	-6.56	-21.5	8.39	-
9 - 8	-2.60	-17.6	12.3	-
9 – 10*	-13.7	-32.0	4.64	-
10 – 1*	-81.6	-99.9	-63.3	+
10 – 2*	-57.4	-75.8	-39.1	+
10 – 3*	-29.8	-48.1	-11.5	+
10 – 4*	-12.4	-30.7	5.94	-
10 – 5*	-4.83	-23.1	13.5	-
10 – 6*	1.096	-17.2	19.4	-
10 – 7*	7.11	-11.2	25.4	-
10 – 8*	11.1	-7.24	29.4	-
10 – 9*	13.7	-4.64	32.0	-

Legend: Values with ranges that include "-" as a value are not significant in such intervals. “*” on the chart indicates a day that only accounts for last day cycle.

Trials

Day-time analysis narrowed how time periods during 8:00 and 20:00 had maintained and compared to other intervals across days and treatments. Across trials differences were not seen in daytime cycles when comparing LSD of means between sets. Tables 8 and 9 present the relationship between each trial with their respective daytime voltages, and tables 10 and 11 represent “night-time” voltages. Figures 22 and 23 detail trials to voltage relationships in boxplots for day and night, respectively.

Treatments

To analyze day/night trends in treatments, data was reviewed and analyzed using least significant differences in means. Tables 12 and 13 represent daytime values and tables 14 and 15 represent night-time values. Boxplots in figures 24 and 25 model data ranges between group by displaying a confidence interval for each group.

Intervals

Day by day analyses focused on day-time periods of collection was organized in a F-grouped tables to provide both the act and degree of shifts that could be occurring during the ten-day period. Tables 16 and 17 are organized using the same lettering system for other variables analyzed.

Averages

Figures 26 and 27 show voltages averaged using LSD means from each trial for all treatments including day and night respectively. The boxplots show a range of values that fell into a confidence interval, where values were most likely to occur based on seen trends. Figures 28 and 29 visualize exact averages of cells for day and night, respectively. Lines are organized by treatment type and demonstrate a rate of change from interval to interval. Day and night were separated to allow for an easier cue on how voltage changed over time, or when cells began to stabilize.

Table 8. Table of values for evaluating means via F-tests, comparing day time means from each trial.

Alpha	0.05
Error-Degrees of Freedom	396
Error Means Square	785
Critical Value of F	1.96
Least Significant Difference	5.81

Table 9. F-tests with least significant difference voltage means, grouped by average daytime values in each trial.

LSD grouping via means per trial (day)

Groups	**Mean (mV)**	**n**	**Trial**
A	99.6	200	1
A			
A	98.4	200	2
A			
A	87.7	200	3

Legend: Means with the same letter are not significantly different.

Table 10. Table of values for evaluating means via F-tests, comparing nighttime means from each trial.

Alpha	0.05
Error-Degrees of Freedom	441
Error Means Square	5710
Critical Value of F	1.96
Least Significant Difference	14.9

Table 11. F-tests with least significant difference voltage means, grouped by average nighttime values in each trial.

LSD grouping via means per trial (night)			
Groups	**Mean (mV)**	**n**	**Trial**
A	37.7	180	1
A	36.3	180	2
A	33.8	180	3

Legend: Means with the same letter are not significantly different.

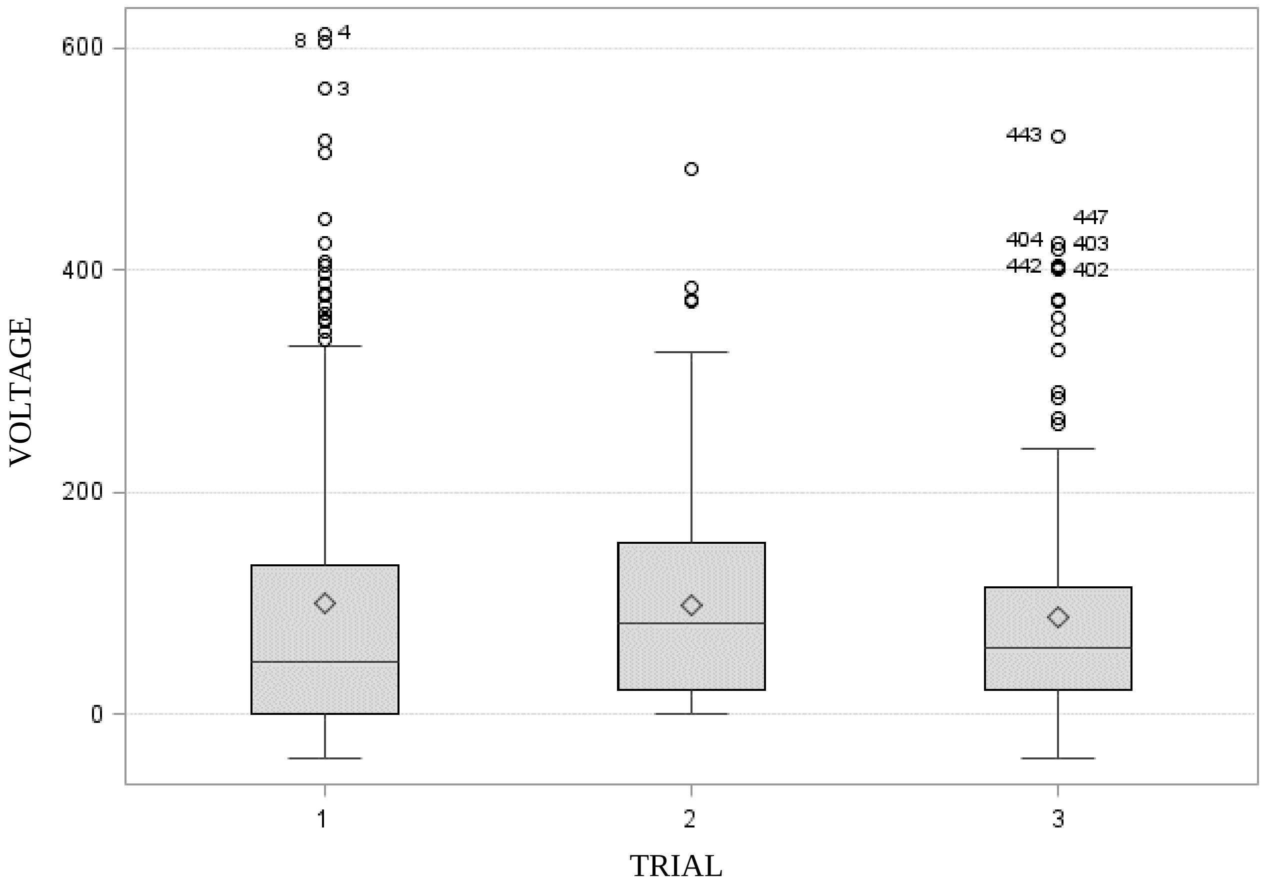


Figure 22. Distribution of daytime means and average voltage for analyses of variance between trials.

Standard deviation is represented via vertical bars.

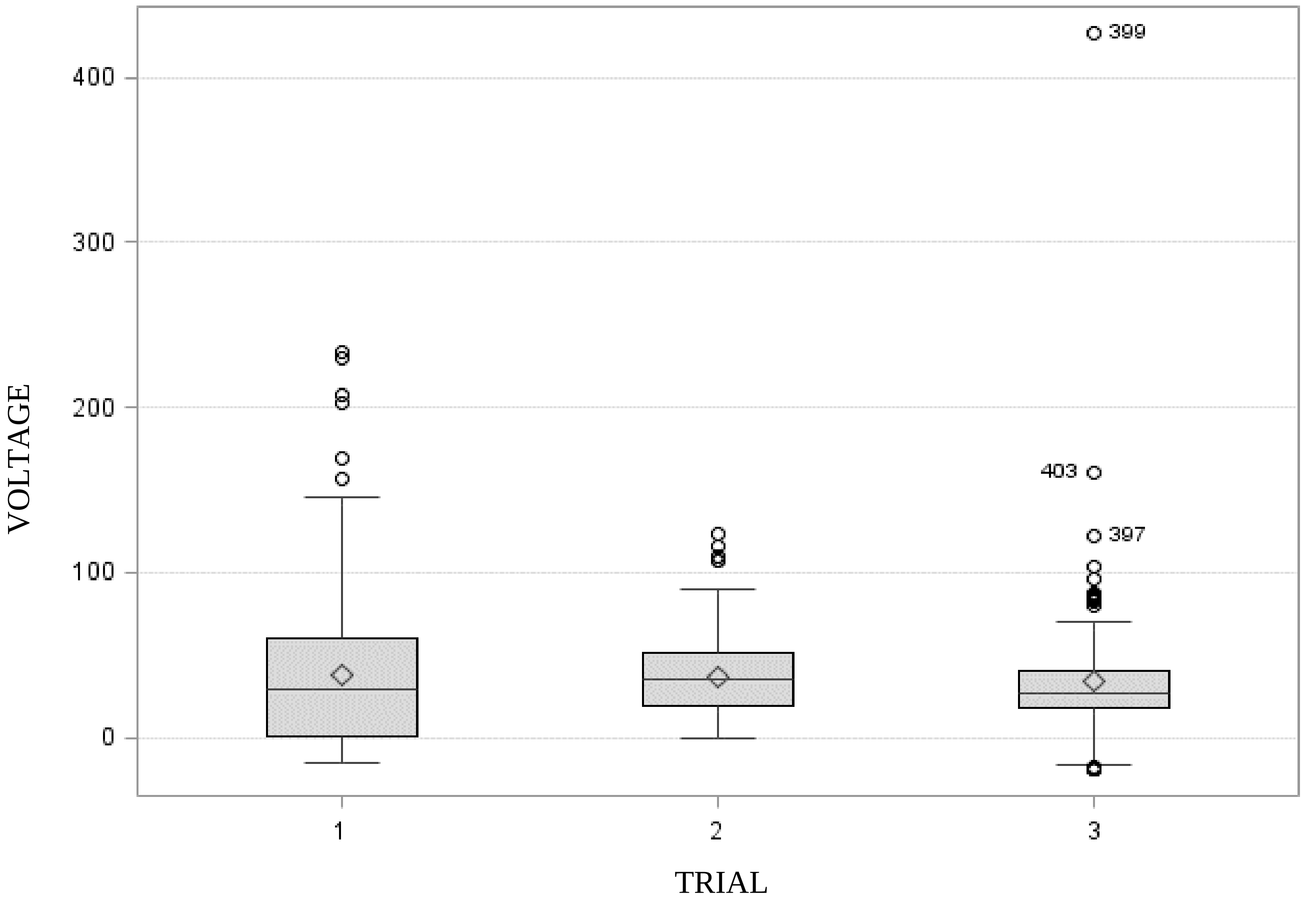


Figure 23. Distribution of nighttime mean voltage for analyses of variance between trials. Standard deviation represented via vertical bars.

Table 12. Table of values for evaluating means via F-tests, comparing daytime means from each treatment group.

Alpha	0.05
Error-Degrees of Freedom	441
Error Means Square	5710
Critical Value of F	1.96
Least Significant Difference	19.2

Table 13. F-tests with least significant difference voltage means, grouped by average daytime values for each treatment group.

LSD grouping via means per treatment group (daytime)			
Groups	**Mean (mV)**	**n**	**Treatment**
A	155	120	HDB (*Equisetum* spp.)
A	139	120	DDB (Diatomaceous earth
B	96.4	120	PDB (Phytoplankton)
C	63.2	120	ODB (Only-dye)
D	22.8	120	CTL (No-dye/Full Control)

Legend: Means with the same letter are not significantly different.

Table 14. Table of values for evaluating means via F-tests, comparing nighttime means from each treatment group.

Alpha	0.05
Error-Degrees of Freedom	396
Error Means Square	785
Critical Value of F	1.96
Least Significant Difference	7.50

Table 15. F-tests with least significant difference voltage means, grouped by average nighttime values for each treatment group.

LSD grouping via means per treatment group (nighttime)			
Groups	**Mean (mV)**	**n**	**Treatment**
A	51.5	108	HDB (*Equisetum* spp.)
A	51.0	108	DDB (Diatomaceous earth
A	46.6	108	PDB (Phytoplankton)
B	23.1	108	ODB (Only-dye)
C	7.34	108	CTL (No-dye/Full Control)

Legend: Means with the same letter are not significantly different.

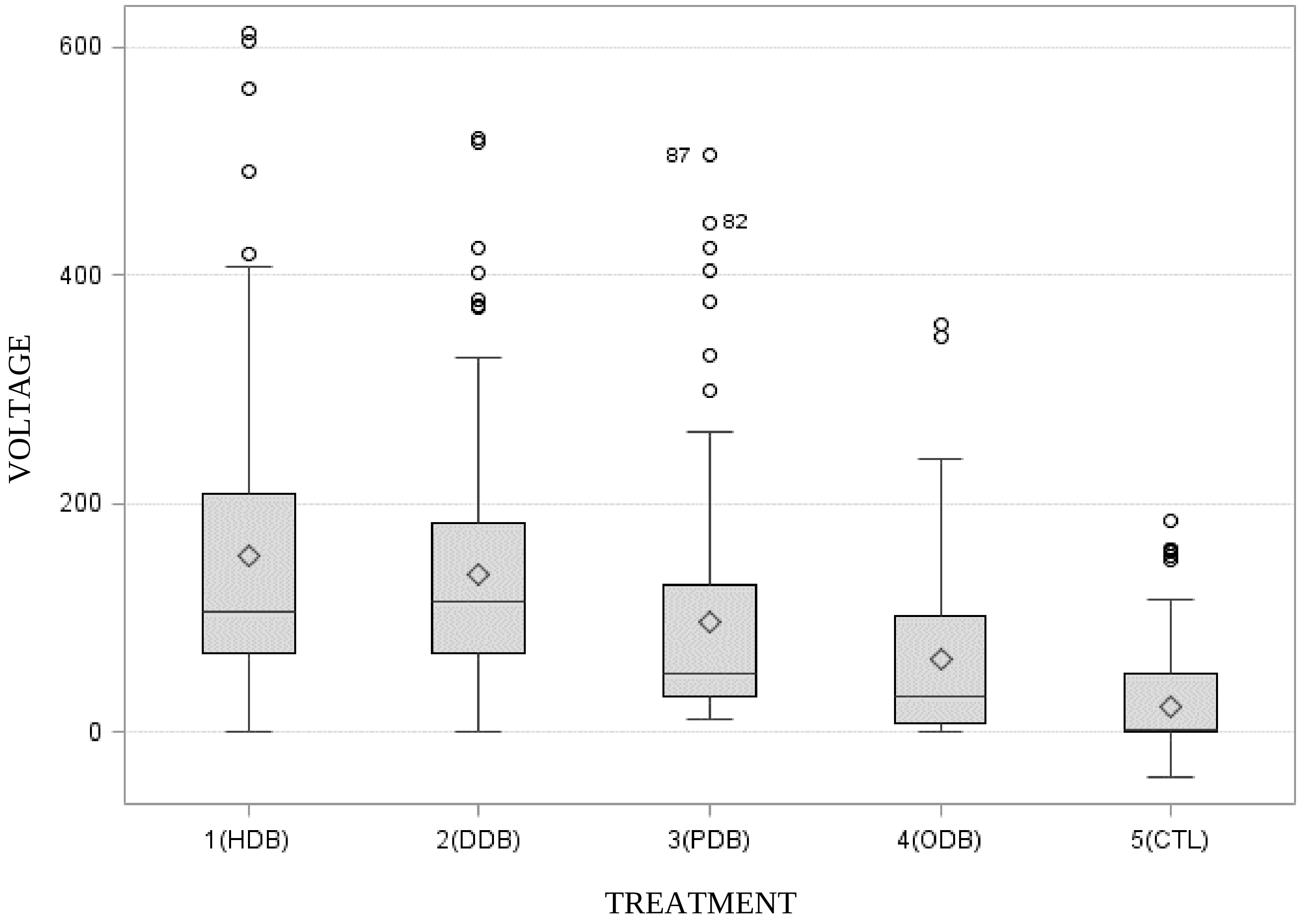


Figure 24. Distribution of voltage for each treatment group, isolating daytime values. Vertical bars represent standard deviation.

Legend: HDB (*Equisetum*), DDB (Diatomaceous earth), PDB (Phytoplankton), ODB (Only-dye control, CTL (no-dye control).

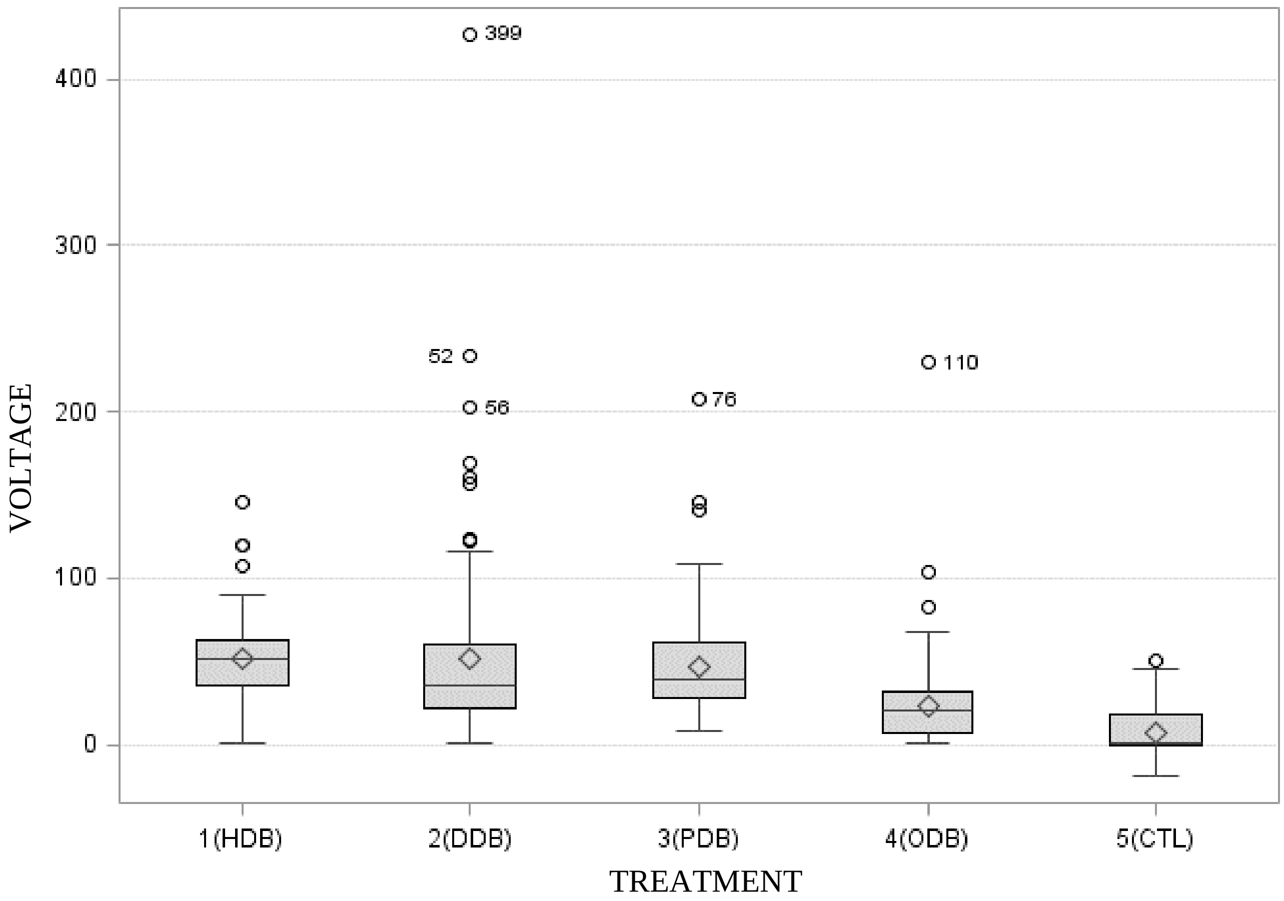


Figure 25. Distribution of voltage for each treatment group, isolating nighttime values. Vertical bars represent standard deviation.

Legend: HDB (Equisetum), DDB (Diatomaceous earth), PDB (Phytoplankton), ODB (Only-dye control, CTL (no-dye control)

Tables 16A and 16B. Organized values by day to evaluate potential significance from one day to another, day (left) and night (right).

LSD grouping via means (Day)					
Groups			**Mean (mV)**	**n**	**Day**
	A		201	60	1
	B		168	60	2
	C		121	60	3
	D		91.1	60	4
E	D		79.4	60	5
E	D	F	71.4	60	6
E		F	61.8	60	7
E		F	56.0	60	8
		F	51.6	60	9
		F	51.0	60	10

LSD grouping via means (Night)					
Groups			**Mean (mV)**	**n**	**Day**
	A		63.8	60	1
	B		49.0	60	2
C	B		40.9	60	3
C	D		35.7	60	4
C	D	E	32.3	60	5
	D	E	28.5	60	6
	D	E	26.0	60	7
		E	23.9	60	8
		E	23.1	60	9

Legend: Letter groups represent similarity between days using LSD between consecutive days. Means with the same letter are not significantly different.

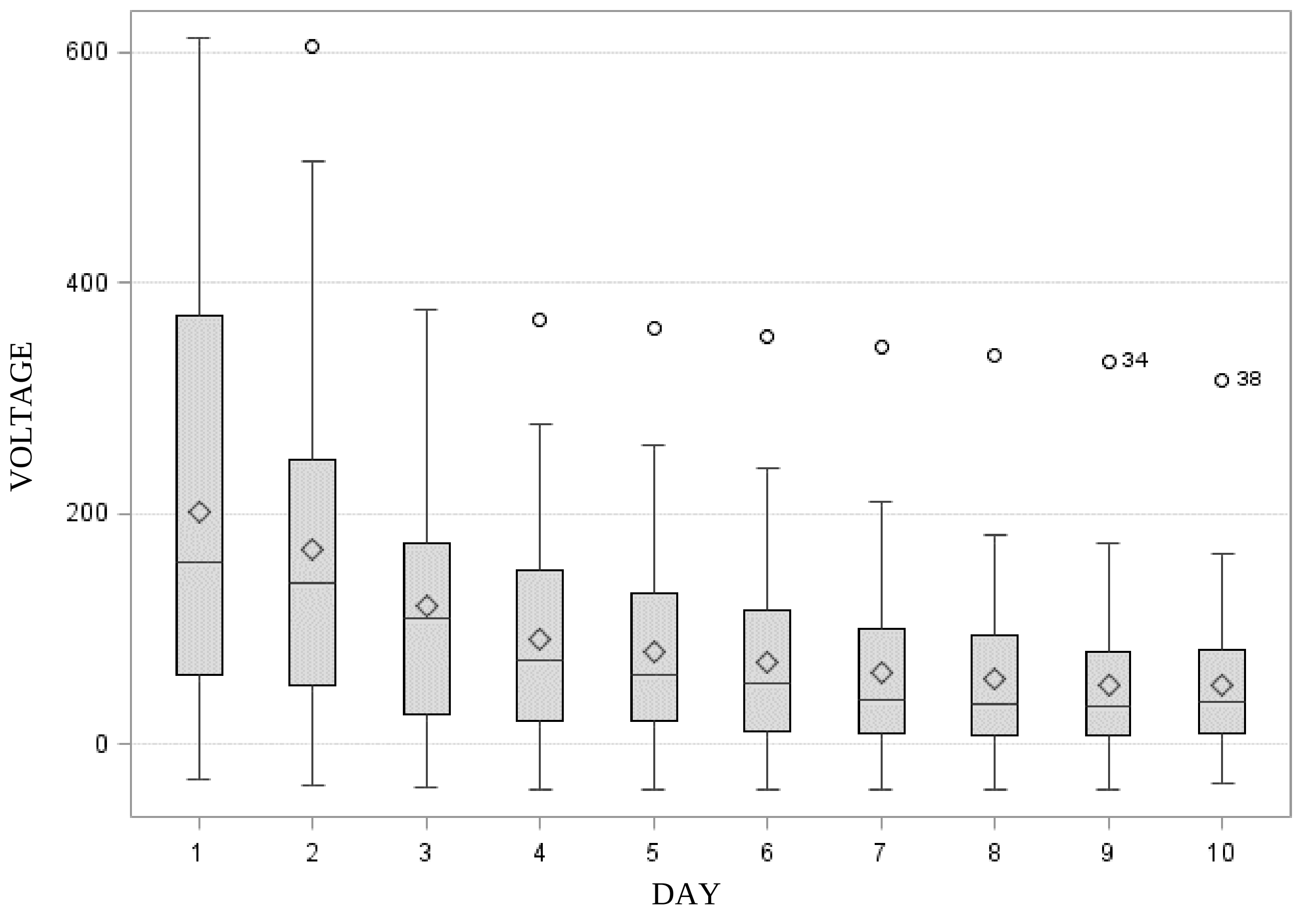


Figure 26. Distribution of voltage for all treatment groups with standard deviation, isolating only daytime values.

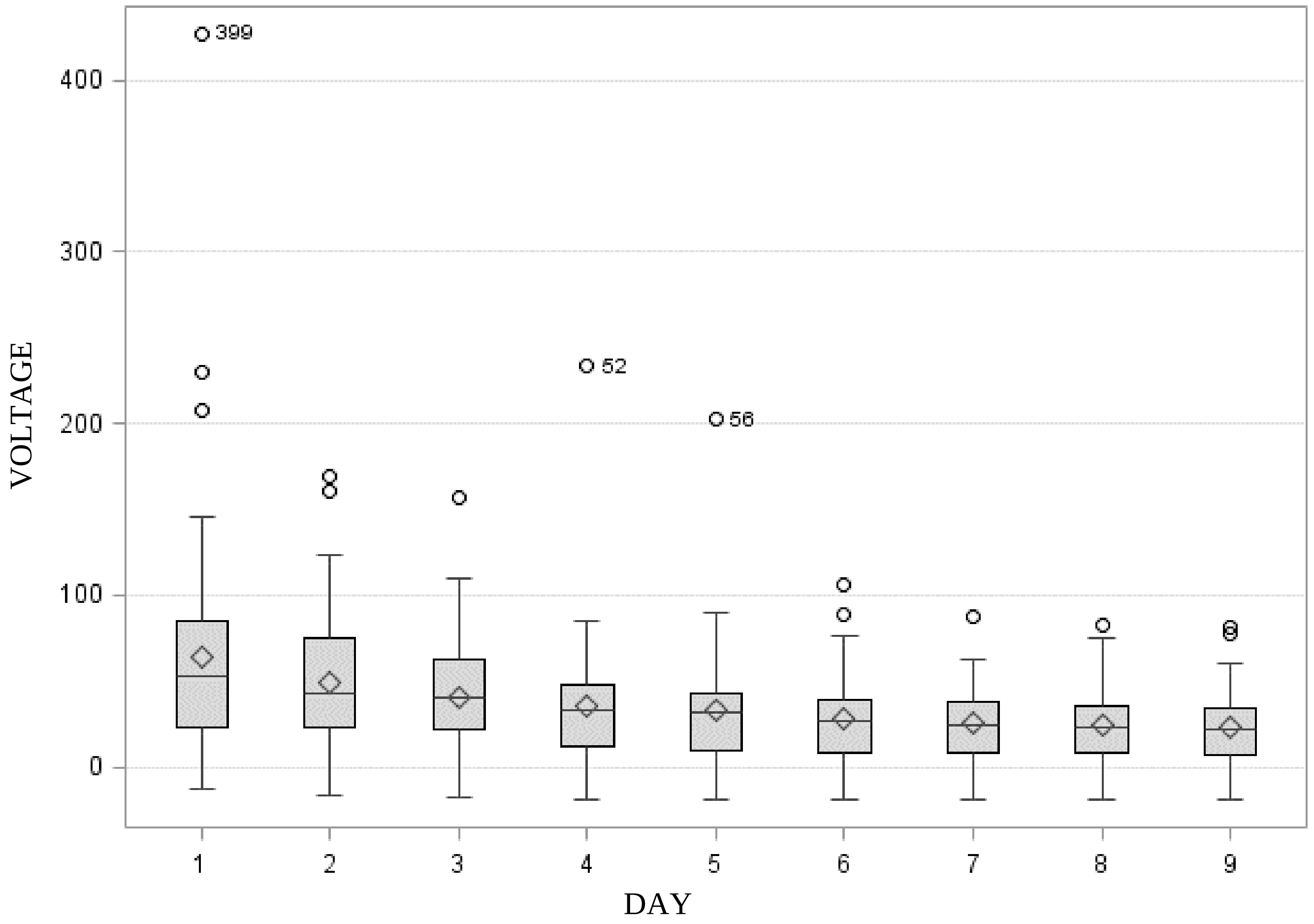


Figure 27. Distribution of voltage for all treatment groups, isolating only nighttime values with standard deviation represented.

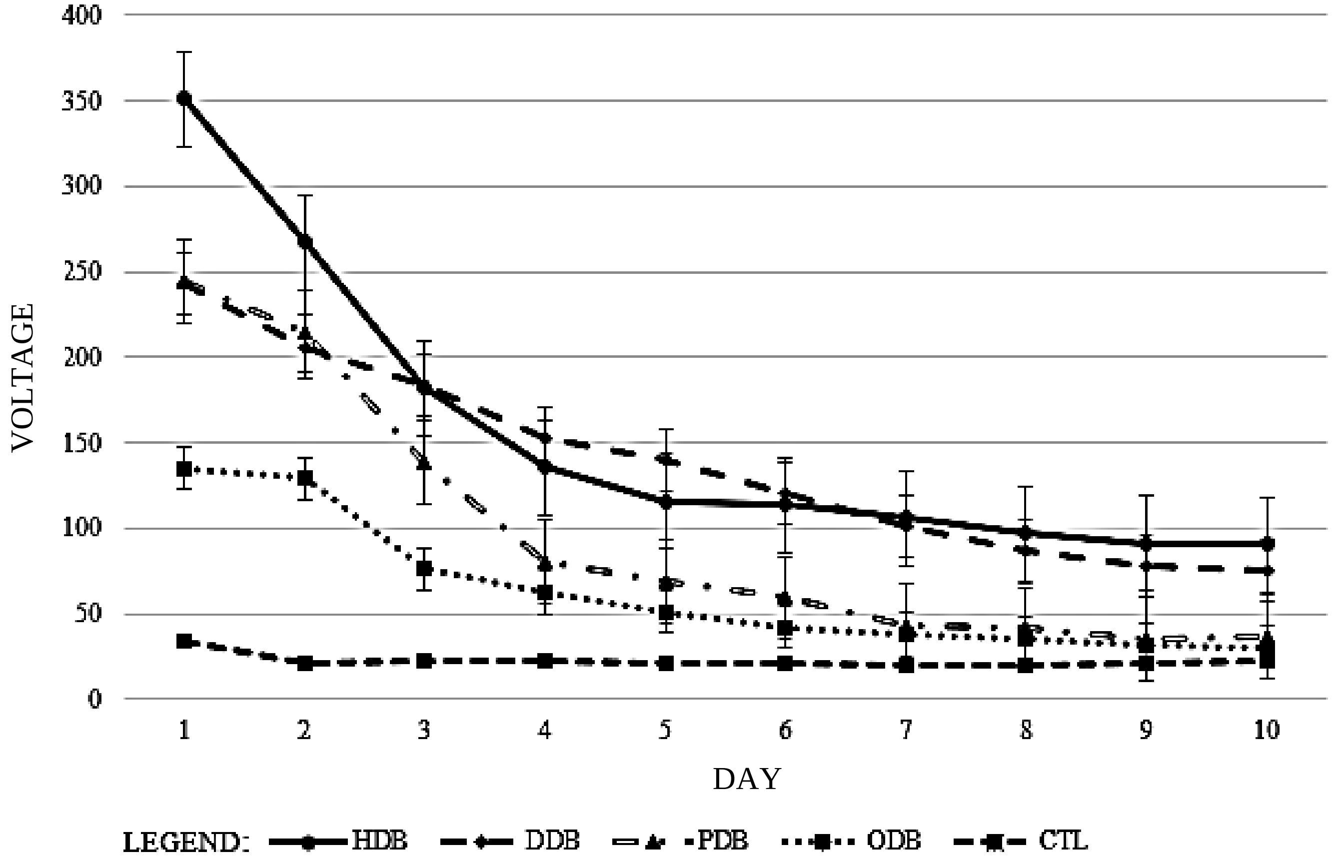


Figure 28. Mean voltage (mV) for each treatment averaged from daytime values in all three trials. Vertical bars represent standard error.

Legend: HDB (horsetail), DDB (DE), PDB (phytoplankton), ODB (only-dye control), CTL (no-dye control)

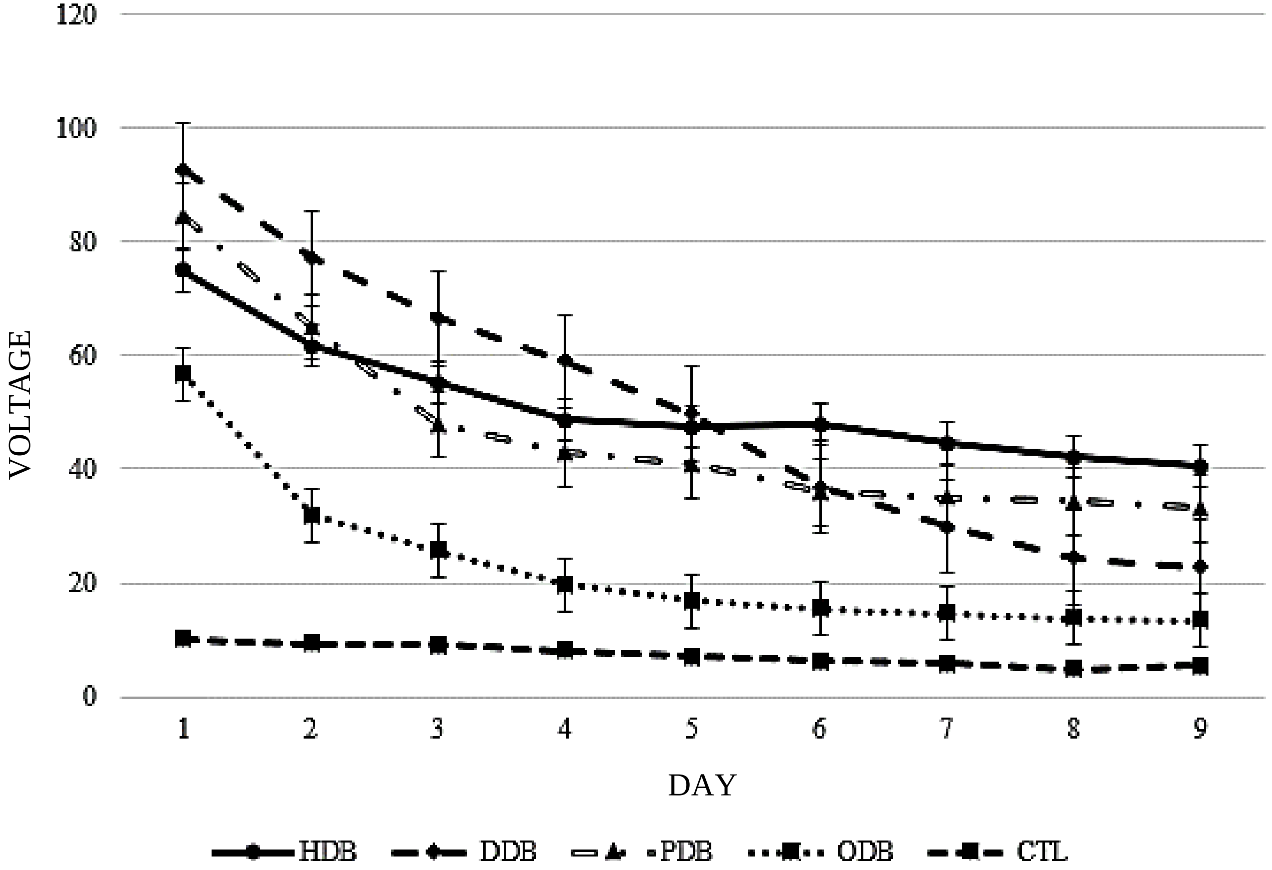


Figure 29. Mean voltage (mV) for each treatment averaged from nighttime values in all three trials. Vertical bars indicate standard error.

Legend: HDB (horsetail), DDB (DE), PDB (phytoplankton), ODB (only-dye control), CTL (no-dye control)

DISCUSSION

Collection

1,140 data points represented either day or night values for five different treatment plans. All three trials performed within equal levels, to not deem one different from another. Exactly 20 cells were done for each trial, for a total of 60 solar cells: 12 in each treatment. For all three trials, horsetail (*Equisetum*) (HDB) and DE (DDB) had similar voltages with some minor differences in some trials. Phytoplankton (PDB) treatments were next in overall voltage followed by the only-dye control (ODB) then the no-dye control (CTL). Looking at day to day comparisons, change in values appeared to happen in the first four days before trends stabilized at lower voltages. Overall, results suggest that the additions did affect the central matrix and outperformed cells without treatments, like ODB and CTL.

Day/Night Findings

Day versus night showed how cells would transition from light to dark reactions, and where specific trends are associated based on light/dark reactions. Once again there were no differences between the three trials to warrant worries about conditions of tests, though total number of values is less in nighttime versus daytime. This is due to a trim of values so that data would be evaluated at the first complete day cycle, thus eliminating the night cycle prior ($n(d) = 600$, $n(n) = 540$). Trials began in the evening after the construction of the cells to evaluate work after immediate fabrication. The evaluation suggested that treatments, when separated by day and night, show similar trends, such as horsetail cells (HDB) and diatomaceous earth cells (DDB) performing similarly through all ten days. Phytoplankton (PDB) cells carried voltages just behind DDB, followed by only-dye cells (ODB) and no-dye cells (CTL) respectively. Difference between days by the F-tests shows days one through four are significant from each other, before beginning the show less consistent difference through later days. Nighttime values for days one through three showed significances from each other, with values after day four starting to flatten and stabilize. HDB, DDB, and PDB mean voltages at night were within bounds to not show significance in differences, with HDB averaging 51.466 mV, DDB at 51.016 mV, and PDB at 46.617 mV: with LSD at 7.4976. ODB scored 23.144 mV and CTL was 7.340 mV during night periods. The importance of this stems from acknowledging a possible effect the treatment groups provided for the components within.

HDB cell for all three trials averaged 155 mV during light periods, DDB with 138.8 mV, and PDB with a smaller 96.407 mV (LDS = 19.178 mV). This interaction may suggest the physical nature of the components are now even further playing a role in how well energy is conducted through the system. Figure 35 highlights an occurrence after the second day with the average PDB cell; a drop that brings once 250 mV to nearly 80 mV. The cells did not show any signs of leakage, nor did the recording system fail. Water from treatment groups or solutions may have evaporated through small leaks and heat from the light to disrupt connectivity after day two. The generally lower value from the PDB could be from that same liquidity and viscosity of the solution disappearing via evaporation.

On day-to-day analyses, Table 7a-d provided a tool for stabilizing trends in an average cell’s values. This type of evaluation can describe if a cell has found a value or a range to stabilize at, or if a rate of change may be seen in cell voltages. Table 7a-d details when days began to stabilize, and where critical moments are observed near or far from its potential limit. When comparing each day-to-day difference in sequence, the trend in change remains significant up until day four and day five values. From here values from days four to nine values are no longer significant from each other. Looking at Figures 35 and 36 both day and night cells on average find a stabilizing point where values do not change drastically from the fourth or fifth day. This trend is confirmed in overall cells looking at Tables 15 and 16 with how days are grouped. Grouping begins to hybridize beyond the fourth day and third night, within a consistent change for days one through three.

Horsetail-based builds generally exhibited high values and supported in analyses of confidence intervals, had a greater average voltage than any other build. Though not significant to suggest separation in performance, it's believed that assistance chloroplasts in a DSSC the available plant material and silica both contributed to the effect of the cell. Silica’s effect should be noted by how well DDB cells performed averaging 138.75 mV in the daytime, compared to HDB cells' 155.07 mV daytime average. Phytoplankton, as shown in Tables 13 and 15, showed significantly higher voltages from both controls, which supported the effect pigments and structural effects from phytoplankton had on light conversion in the DSSC. These three treatments overall had a positive effect on DSSC voltage values across three trials.

Cell integrity is the absolute key to a good cell. As noted with other models, especially the DSSC, leaking of the electrolyte solution has always interfered with the soon marketization and or installation of DSSC-based and similar devices (Sharma et al., 2018). Noted was a fair share of cells show signs of deterioration towards the end of the trial, exhibiting a rough precipitate on expose ends of the cells. Incorporation without prohibiting the work of the electrolyte may be more successful with rougher, more solid-based fillers like silica or plant-materials. The utility of the silica adhesive tape and paste proved to have helped us from preliminary trials, though the adhesive would still occasionally allow for some electrolyte to flow out. Stronger adhesives do exist, though many are costly, toxic to human and eco-exposure, and thus will not fit stipulations of a safe, eco-friendly model. A budget of materials not exceeding more than $500 USD, including upkeep on lighting and solar materials, provided challenges and incentives for accessible equipment. No treatment group had a significant amount of leakage with the cheaper method of sealing, though treatments with horsetail (*Equisetum* spp.) and diatomaceous earth, did not show as much physical deterioration had ensued compared to the phytoplankton treatment, only dye control, and no dye control. Course, silica components did not show to be leaking any electrolyte from out the cell, but instead absorb the electrolyte and confine it to the central zone. Thus, this trend may explain why both diatomaceous earth cell and the horsetail cells have values that maintained an average longer than others did.

The nature of the silica confined the electrolyte to the center and allowed for integration without issues of solubility and larger corrosive effects. Phytoplankton as a treatment was unique, in that the cells had high performances in the initial stages of the trials, most likely due to its chlorophyllin incorporated in the planktonic organisms. Over time these cells had a short life above 200 mV, before falling below 100 mV. This may be attributed to the same dilemma as before, leakage from the center along with the electrolyte; and second, the metal oxide electrolyte oxidizes with the organic components of the phytoplankton, which could dry up and obstruct the connection between the top of the cell and to the other cell.

Working Space

The space between the two halves had a volumetric area around 1 mm x 1.5 mm x 1 mm to be able to hold the dye, electrolyte, and enough material to allow connection from one to another. This space could be focused to a tighter area, though increasing the surface area of the working electrode (WE) would enable higher confidence in electron interactions and allow for better connection between dye and electrolyte. It is important to maintain the contact in the dye/electrolyte interaction and thus to correctly allow for dye to re-enter and recycle into an excited state by light to restart the cell cycle, thus the treatments themselves must not interfere with those components. Horsetail-cells performed and produce a charge, which does suggest that the cell did have a connection between the halves. The horsetail powder was fine enough to enable a consistent mix with the electrolyte. Horsetail cells had a much easier time mixing with more of the electrolyte solution, while the diatomaceous earth treatment required more work to mix the electrolyte throughout the space. The phytoplankton group compares how well smaller levels of bio-silica and chlorophyll would perform compared to a group with chlorophylls (horsetail) and without (diatomaceous earth). The performance of this group shed light on the importance of the connectivity between the cathode and anodes, and how both horsetail and diatomaceous earth provided a bridge for electricity to flow. Phytoplankton cells performed high values in the first three days of the trial, though showed a significant decrease in voltage before remaining at constant value through the rest of the period. When observing how performance between the HBD and DDB groups the central core has a clear role, and a chance for what other potentials exist for upgrading and enabling a better response for electron movement.

Silica Influence

Silica as a semiconductor may be also enabling the directional movement of electrons to the working electrode, though this discussion would gain more ground with a look at efficiency in a later project. When observing the difference between day and night values it was assured that cells did show lower performances in lack of light, though dark reactions that occur without light still maintained as when light was reintroduced, the cell would produce a greater charge. The most similar groups were HDB and DDB groups, most likely due to the silica filling. Horsetail could possibly be integrated onto the working electrode surface as a thinner layer is the space needed or could be reduced without leading to leaks. Diatomaceous earth is another mixture that may also be promising as a very thin layer or element to the working electrode.

Diatomaceous earth's porous nature should be investigated in how well they may absorb a dye, and avenues that address issues with amorphous shapes at a micro-level. The space in the center surrounded by the silica tape is roughly 100 mm^3 and discussions were made to determine whether the space should be greater. Due to the possibility of leakage, the space was kept this size to provide adequate space for horsetail or diatomaceous earth on its working electrode (WE) surface. It is also principle that a larger WE surface enables greater electron injection due to an increased surface area of insertion sites. Direct contact between both electrodes is best to establish a high efficiency of light to electricity in the DSSC (Cao et al., 2018).

The phytoplankton possibly provided an enhancement mechanism to the dye layer as its own chlorophyll was absorbed into the titanium dioxide, though this group alone deserves investigation, especially with the diversity of pigments and dyes present in these phyto-communities. Expanding work into algal groups would be another level of research to perform, where the pigments of some species may indeed be meaningful. Calogero et al. (2014) saw the potential of utilizing invasive algal species as a chlorophyll source for DSSCs. Algae contain a variety of pigments that warrant investigation in this and other solar models. Lim et al. (2015) found what pigments performed better in DSSCs and the relationship between multiple pigments in one cell. Research supports that some cells exhibit enhanced performances when multiple dye or used, like anthocyanins and carotenoid combinations (Ezike et al., 2020). A combination of such enhancing materials could redefine how the model could be approached, though more moving parts may lead to further issues with the relationships between parts (Ezike et al., 2020).

For the Future

Other experiments include to observe the parameters of an experiment with an enhanced connection, or bridge, from end to end, either reducing the space or aiding connection via a biopolymer. Pressure from the clamps exerted on opposite sides closed the space more over time as the adhesive adjusted and flexed. In fact, cells that had been closed for more than two weeks required an acetone/ethanol mix to detached glass plates from the tape to observe the center core. Cells had varying amounts of deterioration either due to cracking or abrasiveness of the working electrode surface. This method and other doctor blade methods have been utilized in many research studies regarding DSSC, but less crude methods like spin coaters and printers exist for these cells at a higher cost. For the number of cells recorded, this process could have helped ensure a cleaner and flatter interface of the working electrode. TiO_2 printing upon the WE could also improve the direction of this experiment with the security of amorphous, non-uniform geography on the slide. What imaging like this does is that it supports the integrity of the WE and accounts for issues in conductive clarity that macro molecules like silica could obstruct. This should be observed in a future project to possible find means to keep the working electrode stabile and effective in longer length trials, including other stabilizers in the cell like polymer additives or polymer-similar materials that are non-toxic and ecofriendly. Biopolymers from seaweed may be an avenue worth venturing, replacing toxic components with readily available and ecofriendly compounds (Bella et al., 2015). Additions to the WE could also include direct diatom infusion into the substrate, which could function as a buffer for electron injection sites (Chandrasekaran et al., 2014).

Last, efficiency studies should be performed, with more time available and stabile resources that support larger utility. This value is critical to confirming the cells ability to control and stabilize itself with light and the load transferring energy around and through the cell. Efficiency can only be solved when cells have resistance accounted, which provide a currency and max value of voltage where the cell can actively manage energy movement. With resistors, this project will be able to determine where solar cells stand regarding the scientific standards of high efficiency materials.

Any further work may market itself more as an educational tool for strategies in research, where crude experimentation leads to an evaluation of cause-and-effect relations with an updated model from previous works. Budget remains a heavy factor in the ability to evaluate different solutions, though this challenge may be more a positive to encourage others to do the same.

Market and Utility Integration

In a world with ever-advancing technology the successes of past work may be indeed a suitable place to define what could be the next best installment into today's use. Competition is rapidly forcing innovation to reach quick heights, sometimes cutting out accessible resources for the most specific of tools to achieve a high standard of utility. Incentives to further a market in a forward manner create a recipe for potential misses and sudden fluctuations of price due to a low supply or high ceiling to access. In the solar industry, companies may struggle to convince the market that such tools are profitable to their business or interests. COVID-19 has illustrated how sensitive the means to manage these markets really are and the harsh realities of nations that may prevent this and other eco-positive opportunities from occurring. Cities around the world have found success in their ability to integrate solar mindfulness into their daily lives, though utility is far from its total potential. Interest must drive not only public utility but the sector of business that supplies commerce and stability. This interest could start at a large public level, where more individuals are aware and fluent with what modern accessible technology is capable of. Until issues with the leaking and the worries and external environment interaction with wildlife, DSSCs will still questioned for its stability (Mozzafari et al., 2017).

Buildings in both urban and rural areas could use the integrated solar cells on glass panel walls, roofs, or externally attached paneling, or indoors with controlled light fixtures (Mariotti et al., 2020). Agriculture could utilize this technology to help provide energy for irrigation systems and shading from excess solar radiation (Roslan et al., 2018). These methods would be useful for replacing greenhouse producing methods and reducing heat stress on crops (Roslan et al., 2018). Note that DSSCs are usually constructed with a square shape, though attempts to make mats of cell (Muklish et al., 2017) or in Casadio et al. (2021) with a demonstrated model that is thin and fibrous as a solid-state cell system. Reducing the rigidity has its costs, as efficiency for these builds are not yet to market and industry standard. (Casadio et al., 2021). Carbon-based DSSCs are also a cheap potential alternative being investigated as a solid-state alternative (Arbab et al., 2020). Funds to establish research for such integration would prove useful for the increasing uncertainties of climate trends. Education at the high school and university level can subscribe to research and lesson plans that enhance the base knowledge of photovoltaics, with worldly applications. All these solutions stem from an acknowledgement of the drawn-out battle with climate change and efforts that minimize the carbon footprint at large scales.

Education

Education on solar solutions is a market critical for the growth in renewal energy avenues and access. Lesson plans may require a focus in cheaper, healthier resources for environment consciousness, due to a supply loss in formerly, affordable materials. Chien et al. (2018) led high school level students to successfully create several DSSCs and provided a thorough discussion of how and why more classrooms should use this exercise.

Kits for solar cells have existed for years through educational programs in chemistry or biochemistry. This parameters of the protocol, was derived from a nanocrystalline solar cell kit from the Institute for Chemical Education to help high school teachers discuss the importance of photosynthesis and human application. Solar technology can be more resourceful in learning if more schools and teacher had access and practice with such materials. Efforts of such scale are still underway, but places have become more capable of solar utility than others, either through monetary incentives or accessibility to land for solar. Work like this research can be done at various scales that will contribute to the message of eco-conscious, while refraining from scarce materials and increasing prices. Before a DSSC model can reach a market, the model must answer for its largest problems, correcting the leaking and leeching into vulnerable ecosystems.

CONCLUSIONS

This effort evaluated how relatively crude resources could work with the central matrix of a dye-sensitized solar cell. Physical adjustments were made to integrate *Equisetum* grounds and diatomaceous earth into the model while also monitoring the effects of each group's own differences. HDB and DDB performed with similar ranges and did promote the transfer of energy, while PDB highlighted the importance of a better bridge system to facilitate more dye/electrolyte interactions. Results suggested that both horsetail and diatomaceous earth have potential applications in their use in photovoltaics, and with both cheap in cost of access a hope remains that more research is done to observe more work with a similar eco-friendly mindset. Refinement methods could repurpose materials to do better work in maintaining reactions of the cell, or potentially amplifying based on increased concentration of photosensitizers and conductive materials. The diversity of plant and algae aids in the paths towards more efficient and economically viable cells with confidence that such materials are available and renewable. Furthermore, this research may find success inside a classroom with guided instruction that motivates critical thinking in modeling systems in science. The impact can strengthen applications to natural systems and how humanity can supply more resources via mimicked processes. DSSCs are a resourceful means to assess the application and implication of materials in a supply-strict time worldwide.

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