Complex Adaptive Systems – Energy Metrologies for Nanobiomaterials in Artifical Photosynthesis

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ABSTRACT

The renweable energy market has been searching for a lighting system that would serve to reduce expenses and harmful emissions in order to cater to our rapid urbanization and increasing electricity consumption, in addition to tending to our weakening environment. A bioluminescent tree incorporates both of these aspects by circumventing electricity dependency and providing a system of greenhouse gas reduction and oxygen production. As the world progresses and becomes more electrically and technologically dependant, people across the globe will adopt the bioluminescent tree for its efficiency and eco-friendliness.

Keywords: bioluminescence, complex adaptive systems, nanotechnology, energy, environment

1 INTRODUCTION

Inefficient, costly lighting systems that are detrimental both to the environment and the economy are far too abundant in this world. The green IT field, which searches for and uses efficient computing resources, holds the answer to this problem, as their systems have "the dimensions of environmental sustainability [and] the economics of energy efficiency" [1]. Systems of this field are needed to replace the current lighting systems and remedy the problems they have caused. Research in Complex Adaptive Systems (CAS) and their biologically inspired capabilities will facilitate creating this replacement.

Multiple millions of street and outdoor lights fill the world and are responsible for 10 to 38 percent of the utility bills for local governments, making nighttime illumination a large expense and consumer of electricity [2]. Considering our rapid urbanization and need for nighttime lighting, installing and maintaining more street lights will become extremely costly and could potentially spiral local governments and economies into a whirlwind of debt, as an average street lamp costs $4000 in installation and over $200 in maintenance [3]. Additionally, this debt is owed to utility companies that use limited, nonrenewable energy sources to power the lights and can charge $100 for electricity per street lamp per year [4]. Generating electricity has been the source of health risks, environmental issues, and energy source depletion since electricity was first harnessed and used.

A few systems have come into the energy market that utilize a sustainable, renewable energy source or use less electricity. However, they do not counteract the effects that we have caused; rather they put off the consequences.

The world needs to find a source of lighting that will reduce our environmental impact while being cost efficient. It must meet a certain criteria from an environmental, energy, and economic perspective:

- For environmental reasons, the public needs a cleaner, cheaper, and simpler system for street lighting.
- For energy reasons, there is a need to conserve our limited supply of nonrenewable sources and switch to renewable sources due to our dependency on electricity.
- For economic reasons, a cost efficient model for energy that does not require multiple steps and parts to pay for is needed.

For these reasons, the renewable energy market has been intensifying efforts to solve these problems that are shared across the globe. The answer to their need lies in a biologically inspired Complex Adaptive System that integrates nanotechnology to create a bioluminescent tree.

2 BIOLOGICALLY INSPIRED CAPABILITIES, COMPLEX ADAPTIVE SYSTEMS, AND NANOTECHNOLOGY

A bioluminescent tree can provide an alternate form of street lighting that is a green IT system to replace traditional street lamps. The intent is to cut back on expenses and environmental harm in order to sustain the world and keep it thriving.

In this particular case, a Complex Adaptive System utilizes nanotechnology and the biologically inspired capability of photosynthesis.

Complex Adaptive Systems work by using multiple interconnected pieces that rely on one another to balance and run as a unified system. They respond to changes in

their environment and take the appropriate actions to adjust to their surroundings [5].

Nanotechnology is "a technology executed on the scale of less than 100 nanometers, the goal of which is to control individual atoms and molecules" [Dictionary.com]. To put this size in perspective, one nanometer is equivalent to one billionth of a meter and would only account for 1 of the 80,000 nanoparticles needed to equal the width of a single strand of human hair [6]. Considering their size, a microscope must be used to work with and manipulate these particles. Nanotechnology opens doors to working at the molecular level and is being applied to multiple industries, especially science and medicine, to create innovative solutions.

Biologically inspired capabilities is the new, revolutionary trend for technological advancements today. These advancements exploit processes that nature has spent billions of years perfecting as their model. They are more efficient and eco-friendly than current systems, and will help our world flourish. These capabilities can be applied to other fields of research, such as CAS and nanotechnology, to create an environmentally friendly and cost efficient solution.

3 BIOLUMINESCENT TREE CONCEPTS

This bioluminescent tree is designed to create luminescence to replace street lamps and outdoor lights, while simultaneously preserving our environment and cutting down on utilities expenses. This innovation cleanses our environment, as it uses carbon dioxide to fuel photosynthesis and emits oxygen as a byproduct. It utilizes no electricity, uses no harmful energy sources, and is a sustainable form of energy that is made directly at the source. This circumvents the reoccurring costs of electricity and distribution which leads governments, businesses, and civilians into a multitude of payments and debt. This Complex Adaptive System uses three main components:

- A constant source of UV radiation to target the gold nanoparticles in the tree to cause fluorescence.
- A collection of gold nanoparticles absorbed and distributed throughout the tree to induce photosynthesis and cause a red light emission from the leaf or location with the highest concentration of chloroplasts.
- A tree to absorb and distribute the gold nanoparticles throughout itself, perform photosynthesis, and create light.

UV radiation, invisible to the human eye and under 400nm in wavelength, acts as the activation energy needed for the gold nanoparticles to fluoresce. Fluorescence is caused when UV radiation comes into contact with certain mediums and produces a visible light. It is characterized by a quick reaction; it rapidly absorbs and re-emits a longer wavelength in particles called photons. This radiation is absorbed by atoms in the medium, exciting the electrons, and moving them to a higher energy, but lower stability level. Due to the fact that electrons tend towards a lower energy level, the energy from the electron is soon given off as heat or transferred to neighboring electrons. When the electron is no longer able to maintain the high energy level, its excess energy is released and it drops back to its original state. This jump of energy states results in an emission of visible light, fluorescence. The visible light emitted from the medium would be of a lower energy and longer wavelength than the UV source according to Stokes law of fluorescence: it states that the light produced by the medium (the fluorescent light) must be of a longer wavelength and lower energy than the light that caused that medium to fluoresce.

The UV radiation would target the gold nanoparticles constantly during the night, resulting in a blue-violet emission from the nanoparticles, causing a red emission from the leaves.

The gold nanoparticles are absorbed by the tree via a solution and are distributed throughout the leaves. They serve as the activation energy and bridge between the UV radiation and the leaf. These nano-catalysts, also known as bio-LEDs, are the fluorescent medium needed to produce high-energy blue-violet light to induce photosynthesis and a red emission from the chloroplasts.

Gold is a mineral capable of fluorescence and emits the color blue-violet when in contact with UV radiation. This is because the wavelength of blue-violet is the energy level right below UV radiation (UV is right before 400nm and blue-violet is right after), and it emits this color in accordance with Stokes law.

The ultimate result in this entire process is the induced photosynthesis and light emission of the tree. Photosynthesis occurs in the chloroplasts in the cells of the trees, with the action taking place in their membranous thylakoids. Pigment molecules, which reside in the thylakoid membrane, absorb a range of colors and convert it into usable energy in their system. Accessory pigments, which accept photons (a quantum of light energy) and pass their energy onto neighboring molecules, include carotenoids and chlorophyll b. This energy is ultimately transferred to the reaction center, containing chlorophyll a (the major pigment), making the antenna complex. Essentially, the antenna complex's purpose is to absorb the light given and convert it into red light. Once the energy is passed on to the reaction center, it becomes ionized due to an electron acceptor, the last portion in a photosystem (a combination of the antenna complex and electron acceptor). Plants contain two photosystems: Photosystem I, also known as P_{700}, works at maximum efficiency when it

absorbs light of 700nm (red); similarly, Photosystem II, also known as P_{680}, works at maximum efficiency when it absorbs light of 680nm (red), which is why all of the energy is converted to red light.

When there is too much light, the antenna pigments continue to convert the multiple colors into red light and send it to the photosystems. The plant must rid itself of the excess energy/red light by emitting it.

Together the UV radiation, the bio-LEDs, and the tree work together to create this revolutionary lighting system. The bioluminescent trees hold a significant place above the current methods, and with the demand for energy growing and the supply of energy shortening, the prospect of conserving energy and opening up doors for renewable sources of energy is an important topic.

4 DEVELOPMENT

These bioluminescent trees offer an innovative solution to our energy related problems, but it too has difficulties that need to be researched further. To start, a tree or variety of trees needs to be found that would keep its leaves year round and produce enough illumination to light a street. The correct molecular size for the gold nanoparticles is a necessity, as the nanoparticle must not kill the tree, but provide enough blue-violet light to cause a red emission in the leaf. A constant source of UV radiation during the night also needs to be installed to ensure that the process is activated and that the correct dosage is used without being damaging. Not only this, but maintenance schedules need to be arranged and timed to determine if it is more cost efficient than a street lamp. The amount of lumens for the amount of light emitted from a source and how much it fades needs to be accounted for, its durability in different climates needs testing, in addition to the toll that around the clock photosynthesis has on the tree.

5 CURRENT STUDIES

There has been limited research on using nanotechnology for bioluminescence, but the few studies show that bioluminescence is attainable, but will take time to develop further. A study was done by scientists at the Research Center for Applied Sciences at the Academia Sinica in Taipei that distributed the gold nanoparticles into a plant named Bacopa Caroliniana. Applying UV radiation allowed them to successfully create a bioluminescent tree. Their research was a large step forward for bioluminescence, but it did not have the proper efficiency needed for commercial use and they were only able to use the Bacopa caroliniana plant. Also, their gold nanoparticles, in the shape of sea urchins, stayed in for only two weeks to two months. [7] A second study conducted at the University of Cambridge use bacteria that contained a genome for bioluminescence to create the light. They found that a culture of bacteria the size of a wine bottle would product sufficient light to read under. Using information for their experiment, they found that to compete with a street lamp, only 0.02% of the light energy absorbed by the plants needed to be used for light emission instead of photosynthesis [8]. Looking into the nanotechnology aspect, using carbon nanotubes and/or a catalyst to split water molecules to produce hydrogen fuel cells using solar power and photosynthetic properties is another possibility [9 & 10].

6 BUSINESS APPLICABILITY

Prices for bioluminescent trees utilizing nanotechnology have not yet been established, but if they can be proven to be efficient and provide ample light to roadways, they have the ability to take over outdoor lighting. Initially, the cost to install these trees might be more expensive, similar to installing solar powered devices, but this product would be worth the additional money. This is in part because there would be no paying for electricity, energy sources, and their associated costs; the same as solar powered light sources. However, the difference is that the bioluminescent tree would also reduce our carbon footprint and add oxygen to our atmosphere immediately after installation. The bioluminescent tree would serve as both a lighting system and an air purifier, compensating for the initial cost of installation. The efficiency and sustainability of this Complex Adaptive System will change our world and help us progress in the following ways:

The environment has been hit hard with greenhouse gases and dangerous by-products. Already, solar panels and energy efficient bulbs are being installed, but that only solves half the problem. The world needs to both cut down on energy consumption and create initiatives to clean our environment. This Complex Adaptive System will be the solution to both halves by running on no electricity or harmful energy sources and reducing carbon dioxide and emitting oxygen. An average mature tree will have a carbon absorption rate of 48 pounds per year and a maximum of about 122.7 pounds per year, and depending on the diameter at breast height (DBH) and species of the tree, it can output anywhere from 6.4 pounds of oxygen per year to 243.2 pounds of oxygen per year [11 & 12].

Several approaches have been developed and implemented to reduce the massive street lighting costs. Normal street lamps have installation, maintenance, and electricity costs, accounting for 10 to 38 percent of local government's utilities bills and are responsible for the third largest consumption of power in local governments [2]. Newer technology with solar panels and LEDs that eliminate or reduce electricity costs are expensive and their benefits are over an extended period of time. However, our economy needs a system that has immediate pay offs. The bioluminescent tree does this, as it immediately begins

working as an air purifier, in addition to eliminating electricity costs. Having more air purifiers will reduce the amount of money spent on initiatives to clean the environment, allowing that money to be redirected into a project that will further stimulate the economy and create jobs.

It is the government's job to organize programs that satisfy the people in their district and to provide a secure community. Agencies such as the EPA, DOI, and DOE are constantly looking for renewable, clean forms of energy to power electronics and protect the environment. Other organizations such as the DOT look for cost efficient systems of lighting for safe transportation, while the DOD desires alternative, cheaper outdoor lights for nighttime illumination on military bases. This product would strike the governments and its associated organizations as especially intriguing considering its sustainability and cost efficiency.

Utility companies, whether the makers or distributors of the electricity, desire cheap systems to make and distribute their products for maximum profit. They also seek to control most of the commercial market and aim to supply their customer's demands for inexpensive, reliable systems. The fact that the bioluminescent tree produces its energy directly at the source, as opposed to receiving electricity from a series of wires from a separate power plant, and is cost efficient would prove a lucrative product and investment opportunity for these utility companies.

Businesses look for cost efficiency in all of their processes to minimize expenses. Many businesses have warehouses or walkways that need to be lit or outdoor facilities that need to be illuminated at night. Additionally, businesses look for products with a lot of potential to invest in and fund, helping advance technologies and stimulating money flow. The bioluminescent tree provides a product for both lighting and financial needs.

A few objectives of a park are to sustain wildlife, preserve natural habitats, and maintain the natural beauty of the landscape. However, hundreds of outdoor lights are used in parks to illuminate pathways for visitors to walk through and travel. Parks would readily adopt bioluminescent trees to meet the aforementioned objectives.

A large source of outdoor lighting consumption stems from civilian use. They utilize lighting systems to illuminate dark alleys and modes of transportation for safety, in addition to lighting for decorative purposes. Whether for a driveway or outdoor patio, civilians buy and install outdoor lights for safety and decoration. However, many civilians are concerned with expenses of electricity, since it comes straight from their paychecks, and would eagerly switch to this product to conserve their money for alternate purposes.

This bioluminescent tree augments existing capabilities in Complex Adaptive Systems, biologically inspired capabilities, nanotechnology, and energy systems. This research provides the world with more advanced technology and will aid in creating more innovative solutions to our world's problems.

7 SUMMARY

The renewable energy market is expanding as the demand for electricity supply increases and environmental awareness becomes more popular. Scientists are trying to develop a bioluminescent tree in order to integrate these two aspects of our society into one. This will allow us to keep advancing in technology, reduce our dependency on limited resources, remedy our environmental and economic problems, and provide a product that can be used by everyone to minimize complications and maximize productivity and benefits.

REFERENCES

[1] San Murugesan, "Harnessing Green IT: Principles and Practices," IEEE *IT Professional*, January-February 2008, pp 24-33

[2] The Blinding Cost of Street Lighting When Purchase Decisions Are Improperly Managed: http://www.dailyenergyreport.com/2011/09/the-blinding-cost-of-street-lighting-when-purchase-decisions-are-improperly-managed

[3] The True Costs of Street Lights: http://www.myledlightingguide.com/Article.aspx?ArticleID=26

[4] Solar Street Light: http://www.gg-energy.com/Solar_Street_Light.cfm

[5] Complex adaptive system (CAS): http://www.businessdictionary.com/definition/complex-adaptive-system-+CAS.html#ixzz22KBlLWOs

[6] Introduction to Nanotechnology: http://www.understandingnano.com/introduction.html

[7] Glowing plants have gold in their veins: http://www.newscientist.com/article/dn19675-glowing-plants-have-gold-in-their-veins.html

[8] Glowing trees could light up city streets: http://www.newscientist.com/article/mg20827885.000-glowing-trees-could-light-up-city-streets.html

[9] Nanotubes bring artificial photosynthesis a step nearer: http://www.newscientist.com/article/dn14297

[10] Artificial Photosynthesis Breakthrough: Fast Molecular Catalyzer: http://www.sciencedaily.com/releases/2012/04/120412105430.htm

[11] Ask Mr. Smarty Plants: http://www.wildflower.org/expert/show.php?id=1634

[12] Oxygen Production by Urban Trees in the United States: http://nrs.fs.fed.us/pubs/jrnl/2007/nrs_2007_nowak_001.pdf