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Bio-solar Cells Mimicking Photosynthesis for Green Energy

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Abstract

Increasing energy demand has led to the increased emission of carbon dioxide into the environment due to burning of fossil fuels, resulting in catastrophic climate change. Scientists are now trying to mimic nature to produce clean and inexpensive energy with less carbon dioxide emission. One such effort is production of electricity and hydrogen by artificial or bio-engineered photosynthesis. A basic bio-solar cell mimics photosynthetic light and dark reactions. The concept is based on the optical absorptive properties of photosynthetic pigments. The processes involved are photon collection, energy conversion and CO_2 sequestration. Photons are absorbed by chlorophyll molecules. Excited electrons are pulled from the triplet excited-state chlorophyll and trapped in a positively charged site. Chemical processes such as synthesis of glucose and other carbohydrates are driven by trapped electrons. A conductive material is sandwiched between layers of chlorophyll to conduct electrons and produce electric current and hydrogen. This electric current and hydrogen thus produced – when combined by bioenergetic energy converters and CO_2- fixing enzyme reactors – generate NADPH and ATP. Bio-solar cells are generally made from spinach chloroplasts and algal/bacterial chlorophylls. The electrical output efficiency of bio-solar cells is lower than that of semiconductor cells. Furthermore, there are many challenges in the production of bio-solar cells. However, this is one of the most promising areas in green energy development.

Keywords— ***Bio-solar Cells, Photosynthesis, Green Energy***

I. INTRODUCTION

Global energy demand is steadily rising in concurrence with the increase in human population. Currently, fossil fuels provide around 80% of the world's energy [1]. Burning of fossil fuels releases enormous amount of CO_2 into the atmosphere, increasing global warming. Hence scientists are in pursuit of producing energy with reduces emission of greenhouse gases. One such effort is to develop bio-solar cells which mimic nature to supply greener energy. The average energy provided by the sun is approximately 1,000,000 Terawatt (TW) against a yearly demand of just 14 TW, i.e. 1 hour of sunlight falling on earth provides energy approximately equivalent to the gross amount of energy used by man in a year [2]. Photosynthesis generates an annual dry biomass of 100 billion tons and mean energy storage of approximately 100 TW, with just 0.1% of energy conversion efficiency. Mimicking photosynthesis to produce non-polluting renewable energy using bio-solar cells involves production of robust artificial systems which can split water efficiently using energy from sunlight and release hydrogen or use the hydrogen released to reduce CO_2 to liquid form of fuels. With the recent advancements in the understanding of the molecular mechanism of the water-splitting complex and photosynthetic energy conversion, multidisciplinary efforts are being taken up to develop bio-solar cells with increased energy conversion efficiency of at least 10% [3].

II. PHOTOSYNTHESIS – A BLUEPRINT FOR BIO-SOLAR CELLS

During photosynthesis, photosynthetic pigments in plants trap photons with a wider range of wavelengths – from visible and near-infrared regions. The pigments are arranged in a unique way to channel the photon energy into reaction centres with higher efficiency. The energy from sunlight is converted into electrochemical energy in the reaction centre which drives the production of carbohydrates from water and CO_2. The process of photosynthesis includes light and dark reactions. Light reactions involve photosystem I (PSI; P700) and photosystem II (PSII; P680) which are located in the thylakoid membrane of the chloroplasts. Sunlight absorbed by the antenna molecules are efficiently funneled into the PSII reaction centre where charge separation occurs, generating electrical energy from light energy. A radical pair state of $P680^{+}P700^{-}$ will be formed where P680 is a reaction-centre chlorophyll *a* molecule and pheo is a pheophytin *a* molecule. Splitting of water is mediated by $P680^{+}$ produced in PSII. A catalytic centre comprising a cluster of four manganese ions and a calcium ion (Ca^{2+}) donates electrons to $P680^{+}$ to split water molecules. Four electrons are required for splitting of water into dioxygen and reducing equivalents; this implies that PSII should trap four photons for the reaction.

Equation 1:

$$2\,H_2O \xrightarrow{4h\upsilon} O_2^{-} + 4H^{+} + 4e^{-}$$

The electrons from $Pheo^{-}$ are transferred through cytochrome b6f and plastocyanin to PSI (P700), where the electron is further excited by P700 to generate a redox potential of -0.7 V. Therefore sufficient energy is accumulated to generate the reducing equivalent nicotinamide adenine dinucleotide phosphate ($NADPH_2$) and adenosine triphosphate (ATP). The reducing equivalents and ATP thus produced are utilized for synthesis of carbohydrates.

Equation 2:

$$CO_2 + 4H^+ + 4e^- \xrightarrow{4h\upsilon} (H_2CO) + H_2O$$

Adding equation 1 and 2 gives the overall reaction of photosynthesis

$$CO_2 + H_2O \xrightarrow{8h\upsilon} (H_2CO) + O_2$$

Although the energy conversion efficiency of natural photosynthesis is low, it can serve as a blueprint for new-generation bio-solar cells. In plants, two photosystems act in tandem to drive splitting of H_2O and CO_2 reduction. The same can be done in artificial systems with higher efficiency. In plants the photosystems compete for light of the same energy level and the infrared photons are left without use. In artificial photosynthesis, cutoff wavelengths of 700 and 1100 nm can be used in tandem so that infrared photons can also be harnessed effectively [4].

III. BIO-SOLAR CELLS

A bio-solar cell is basically made of a coating of photosynthetic pigments, which when exposed to sunlight produce electrical energy (Fig. 1). Although there are different types of bio-solar cells, they are generally made from reaction centres of photosynthetic bacterium *Rhodobacterium sphaeroides* [5], spinach [6] or the cyanobacteria *Synechocystis* sp. PCC 6803 [7]. The reaction centres are coated on the surface of a carbon electrode. An aqueous electrolyte is applied to provide plant-like conditions. To ensure that the device is complete a counter electrode is used. When sunlight strikes the reaction centres, they release electric charge. The electrodes adhering to the reaction centre collect the negative charge, and the ions present in the electrolyte transfer the positive charge to the counter electrode. Thus the two electrodes develop an electrical potential and supply electrical energy similar to a battery [8].

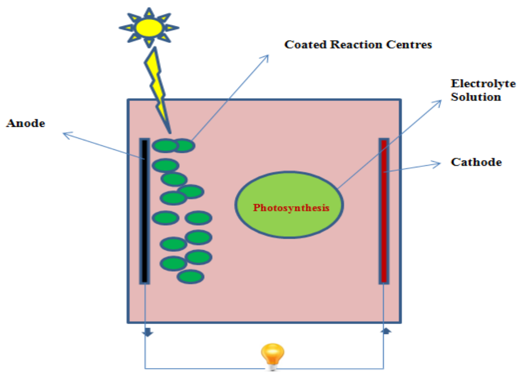

Fig. 1. Model of a Basic Bio Solar Cell

The bio-solar cell generates electricity throughout day and night. Researchers were able to generate a maximum power density of 0.9 mW m^{-2} from a bio-solar cell through photoc reactions of *Synechocystis* sp. PCC 6803[7]. Mershin and his colleagues extracted the PSI (P700) from plants, stabilized them using surfactant peptides and coated them onto a glass substrate which produced electric current when exposed to sunlight [8]. In addition to generation of electricity, polymers with higher efficiency can be synthesized by coupling bio-solar cells with CO_2-fixing enzyme reactors [9].

IV. CONCLUSION

Bio-solar cells have the potential of being used in a broad range of wireless applications, especially in remote areas. As their performance is low, they are not being used widely in commercial applications. But considering the reduction in emission of green house gases biosolar cells are viable alternative to fossil fuels. Also with recent advancements in bio-solar cells, with self-assembly and self-repairing properties, the efficiency can be improved greatly.

As Mershin implies, within a few years a villager from a remote location without electricity would just have to take a bag of chemicals that stabilize the photosystem I molecules, mix them with anything green and paint it on the roof to start producing power which could light lanterns and charge cell phones [10]. This scientific achievement was envisioned by Professor Giacomo Ciamician around a century ago in 1912 as follows "On the arid lands there will spring up industrial colonies without smoke and without smokestack; forests of glass tubes will extend over the plains and glass buildings will rise everywhere; inside of these will take place the photochemical processes that hitherto have been mastered by human industry which will know how to make them bear even more abundant fruit than nature, for nature is not in a hurry and humankind is" – published in *Science* [11]and his vision is being made a reality by the discovery of bio-solar cells.

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