Bio-Photovoltaic: The Future of Electricity with Natural Resources

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Abstract

Electricity crisis is one of the biggest problems faces of the world which increases day by day. Today's several sources are used for electricity generation but the by-product of them is highly toxic to human being and ecosystem. The simplest form of electricity, due to the presence of an electric charge which uses positive and negative ions, produces an electric field. The motion of electric charge is an electric current produces in complete resistors. The bio-photovoltaic cell is recently developed as an alternative technology which uses plant, fungi, moss and bacteria etc, to harness solar energy as a catalyst in plant rhizosphere to generate electricity. This technology may possibly be used as the method for electricity generates and makes an eco-friendly product and renewable fuels. The bio-photovoltaic cell system is consist of biological material that produced electrons through the process of photosynthesis due to which many electrons undergo oxidation of water transfer in electrodes through complete circuits. Many substrates involved in the production of electricity including organic or inorganic component used as provided for in biophotovoltaic cell system. These electrons are collected by using conductive electrodes which produces electricity. Hence, it is also known as bio-electrochemical device systems that convert to chemical energy into electrical energy that functions in a way similar to the microbial fuel cell. The current review paper emphasizes on the production of electricity through exploiting photosynthesis and the biological material that play a vital role production of electricity by using bio-photovoltaic cell system with natural resources.

Key-Words: Bio-Photovoltaic Cell; Photosynthesis; Bio-Source of Electricity; Electricity Generation.

I. INTRODUCTION

The demand for energy is increasing worldwide that causes energy crisis and environmental pollution too Parkash et al. (2016). Still, an estimate of over 67% of electricity is produced from coal, oil or natural gas. Therefore, most of the researchers undergoing on harnessing electrical energy from renewable and sustainable sources like solar, wind, water, nuclear and biomass. In the present time world-wide electrical energy is obtained from nuclear reactors (13.4%), hydropower, wind (16.2%), solar and biomass (3.3%). Bio-photovoltaic devices are the innovative framework for sustainable bio-electricity products. Due to rapid demand of fossil fuel for production of electrical energy, the sources are decreased and generate toxic compound that impact on environment. Therefore, the alternate mode of electricity production through bio-system which is rapidly evolved field of science and technology especially for developing countries those are facing severe energy crisis Bond et al. (2003). The bio-photovoltaic device widely used for generation of electricity by using sunlight during the photosynthesis of plant (including cyanobacteria, algae, and vascular plants). The bio-photovoltaic is composed of several biological materials and consist of electrode and also an electron that traps from the system produced electricity in circuit Bombelli et al. (2011). This system also contain bacteria inside the fuel cell which are decomposing bacteria that change waste material into organic matter present that help in production of electricity. From last few years, the bio-photovoltaic device concept has been systematically improved and leads to the high demand for their electricity production through the biological photovoltaic system. The bio-photovoltaic system is also known as microbial fuel cells or living solar cells Rosenbaum et al. (2005). The bio-photovoltaic device was first developed by Bombelli in 2011 by using *P. Patens* for production of electricity Bombelli et al. (2011).

II. PHOTOSYNTHESIS

Photosynthesis is the process used by plants, algae and other organisms to convert chemical energy into electrical energy from the sun that released to fuel. This chemical energy is stored in carbohydrate molecules such as sugar, which is synthesized from carbon dioxide and water in presence of chlorophyll, to make glucose and releases oxygen. A general equation for photosynthesis is given below: (Sudhakar, Rajesh and Premalatha, 2012)

$$6CO_2 + 12H_2O + \text{Photons} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Photosynthesis reaction takes place through several steps which occur during two stages: a series of light-dependent reactions that are temperature-independent and a series of temperature-dependent reactions that are light independent. The rate of first series, called the light reaction, can be increased by increasing light intensity but not by increasing temperature. In the second series, called the dark reaction, rate can be increased by increasing temperature but not by increasing light intensity. The first photosynthetic organisms most probably involve in the evolutionary history of life. But mainly reducing agent used as hydrogen and hydrogen sulphide, relatively to water, as sources of electron (Olson et al. 2006).

III. MECHANISMS OF ELECTRON TRANSFER IN BPVS CELL

The bio-photovoltaic cell is consist of the biological sources like plant, moss and algae etc, which are produced electrons through the process of photosynthesis or cellular respiration in microbes or entirely as a result of respiration in other bacteria (McCormick et al. 2015). There are two reactions that occur during the process as given below:

$$H_2O + CO_2 \rightarrow (CH_2O) + O_2 + e^- + H^+$$

$$(CH_2O) + O_2 \rightarrow H_2O + CO_2 + ATP + e^- + H^+$$

During the photosynthesis process in green plant and algae which release some organic compounds like carbohydrate, protein and lipid and that organic compounds decomposed by soil bacteria which produces electrons Bryant et al. (2006). This electron is produced resulting in creation of photon with different experiments are different results according to the sites whereas electron leaves in the electron transport chain system for after PSI and before PSI (Bombelli et al. 2011; Calkins et al. 2013). The electron transport chain during of photosynthesis initiated by absorption of light by P^{680} chlorophyll α provides the energy to split water and free an electron**.** The acceptor of electrons leaves in the photosystem II through a series of electron mediating molecules, pumping protons system and passed along-with pheophytin (pheo), quinone A/B (QA/B), plastoquinone (PQ), cytochrome b6/f (Cyt bg/f) and plastocyanin (PC) McCormick et al. (2013). After that electron receives energy added from a second electron transport chain of photosynthesis is excited by absorption of light by P^{700} chlorophyll in photosystem I, where it is used to generate NADPH for CO_2 reduction. In BPVs cell, electron can be trapped a number of sites in the electron transport chain and then redirected through an applied electrical in system. Bombelli et al. (2011) demonstrated through the use of photosynthetic inhibitors that the electron mediating compound ferricyanide picks up an electron after the production of NAD (P) H at the end of the electron transport chain.

IV. MODE OF BIOLOGICAL PHOTOVOLTAIC CELL

The biological photovoltaic system is divided into anodic and cathodic chamber. The oxygenic photosynthetic biological material is like purified photosystem or whole algal or cyanobacterial cells use in the anodic half-cell has shown Figure 1 McCormick et al. (2013). The production of higher electrode in cathode chamber relative to reduction of anode drives current into external circuit. In photovoltaic system energy is stored as a potential driving between electrodes thus can be used as electronic device (Driver and Bombelli, 2011). When a nonbiological material or any nanomaterial that is used with biological component are joined and illuminated, electrons are transferred to the nanomaterial to produce electricity. The photovoltaic-driven electrolysis of water occurs due to magnificent electric current between the electrodes with electrical energy supplied by the photovoltaic cell. The free energy and Gibbs free energy give the small amount of total energy in system that available for useful work also known as chemical potential. The change in free energy is denoted as (ΔG°) and free energy needed to split H_2O into H_2 and O_2 is equal to 1.23 eV Moore et al. (2011). Biophotovoltaics devices utilize this charge separation to generate electrical energy. BPVs included a wide variety of subcellular or cellular photosynthetic components such as purified oxygenic photosynthetic reaction centres like photosystem II (OPRCs) Yehezkeli *et al*. (2012), thylakoid membrane (Bombelli et al. 2013; Chiao et al. 2006), cyanobacteria or green algae (Calkins et al. 2013; McCormick et al. 2013). There are several types of photosynthetic microbes and plants are used in bio-photovoltaic system for production of sustainable electricity generation and eco-friendly. The list of remains microbes used in biophotovoltaic display in Table1 Samsonoff et al. (2013). Similarity, Wei et al. (2015), was observed electricity produced with nine cells connected in small series of bio-solar panels in stack array format. Due to which connection of the nine connected with bio-solar panel for generation of electricity approxs 5.59μm and continuously electricity produced during from bacterial activities.

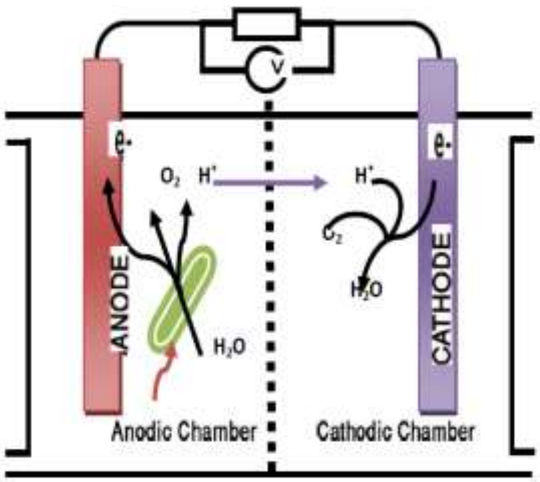

Figure 1: A schematic diagram of worked onto bio-photovoltaic device McCormick et al. (2013).

Table 1: Photosynthetic microorganisms widely used in BPVs Samsonoff et al. (2013)

S.No.	**Microbes**	**Microbial type**
1	*Anabaena variabilis* (Chiao et al. 2006; Tanaka et al. 1985).	Cyanobacteria
2	*Chlamydomonas reinhardtii* (Rosenbaum et al. 2005).	Microalgae
3	*Chlorella vulgaris* (McCormick et al. 2011; Powell et al. 2009; Powell 2009).	Microalgae
4	*Dunaliella tertiolecta* (McCormick et al. 2011).	Microalgae
5	*Rhodobacter sphaeroides* (Rosenbaum et al. 2005; Takshi et al. 2010).	Purple Bacteria
6	*Synechococcus sp*. (Furukawa *et al*. 2006).	Cyanobacteria
7	*Synechococcus sp*. PCC7942 (Tsujimura et al. 2001).	Cyanobacteria

8	*Synechococcus sp.* UTEX2380 (Rosenbaum et al. 2005).	Cyanobacteria
9	*Synechococcus sp.* WH5701 (McCormick et al. 2011).	Cyanobacteria
10	*Synechococcus sp.*PCC6803 ((McCormick et al. 2011; Zou et al. 2009).	Cyanobacteria
11	*Synechococcus sp.*PCC6714 (Yagishita et al. 1999).	Cyanobacteria

V. BIO-SOURCE OF ELECTRICITY

The bio-electricity sources are increasing demand for changing the impacts of global warming. This is most common form of renewable energy, so mainly used in recently that produces high-energy to replace in conventional fossil fuel energy sources. Hence, a variety of microbes and plant are used for generation of electricity by using various innovation technologies or method as follows:

5.1 Bio-Generation of Electricity by Plant

The concept of vascular plant bio-photovoltaics (VP-BPVs) is based on microbial fuel cells device (MFCs). It is a recently, developed technology that uses higher plants to harvest solar energy. The metabolic activities of heterotrophic organism in plant rhizosphere to generate electricity using *Oryza sativa* (rice) and *Echinochloa glabrescent* and *Oryza sativa* have been selected because it is one of the world's most important agricultural crops and cultivation in large area approximately 150 million hectares worldwide (IRRI, 2012). The VP-BPVs consist of operation in anodic half-cell like: (a) vascular plants are able to harness light energy to perform carbon fixation and subsequently produce exudates from the root systems (b) a self-established population of heterotrophic bacteria living in the plant rhizosphere for oxidation of root exudates (c) a three-dimensional network of carbon fibre surrounding the root system for collecting electrons generated from activities of the soil bacteria. The electrons generated in the anodic chamber was then consumed in the cathodic half-cell through reduction of electron acceptor ferricyanide ($[Fe\ (CN)_6]$) to ferrocyanide ($[Fe\ (CN)_6]^{4-}$) Bombelli *et al*. (2013). Similarity, The Plant based microbial fuel cells (PMFCs) are recently developed technology for generating renewable electricity which uses non-vascular plants for production of electricity. The plant microbial fuel cell was first published in international plant power symposium in Ghent, Belgium in 2011 by using forest non-vascular plant *Dicranum montanum* for producing green electricity and is also known as bryophytes microbial fuel cell (bryo-MFCs) Potter et al. (1911). This technology is based on vascular plant biophotovoltaic device and the best technique developed for production of electricity because it uses the sustainable energy supply as a substrate and utilized waste material.

5.2 Generation of Electricity by Microbes

The microbial fuel cell (MFC) is bio-electrochemical systems in which bacteria act on the waste organic material and helps in generation of electricity. Thus, bacteria are self-replicating and catalyst for organic matter, oxidation is self-sustaining Bombelli et al. (2013). Earlier, it was thought that only few microorganisms which can be used to produce electricity. But recently, it was observed that most of microorganisms may be utilized in MFCs as studied and shown in Table 2. Potter, (1910) also observed the production of electricity used by living cultures of *Escherichia coli* and fungus genus by *Saccharomyces* by using platinum electrodes. The microbial fuel cell consists of two chambers that are operated as a completely mixed reactor. The anode chamber that holds the bacteria that degraded organic matter in an anaerobic environment. Cathode chamber holds the conductive saline solution and bacteria present in anode chamber produce protons and electrons through oxidation of water and proton exchange membrane that separates anode and cathode chamber which from protons in the solution at the anode driven through the proton exchange membrane separate electron at the cathode to produce electricity in external circuit (Li et al. 2013; Park et al. 2000). These technologies are the production of electricity is commonly found in most of fuel cells like battery cells, hydrogen fuel cells etc. which are capable of producing electricity. The exploration of various type of material which are used in electrodes that balance efficiency and cost-effectiveness are having important roles of the potential, large-scale use of MFCs particular in wastewater treatment plants which is hoped to be a power generation plants as similar to a power consuming plant.

5.3 Generation of Electricity by Bio-Hydrogen Production

Hydrogen fuel cell is similar way of method for production of electricity by MFCs. This system also consist of bacteria that act as catalysts and oxidized substrates present in anodic chamber thereby producing electron and proton which are transfer to the cathode in external resistor with the help of proton exchange membrane (PEM), respectively. Both of them combine with oxygen to form water. Hydrogen generates from proton and electron produced by metabolic activity of microbes in MFCs for production of electricity. The main advantage of this method hydrogen accumulated and stored for later used to overcome the naturally low power feature of the MFCs. Therefore, MFCs is provided a renewable hydrogen source that can contribute to the overall hydrogen demand in the economy Holzman et al. (2005).

Table 2: Details some of different microorganisms, substrate and mediator used for MFCs operation Samsonoff et al. (2013)

Microorganisms	Substrate	Mediators
Actinobacillus succinogenes	Glucose	Neutral red or thionin as electron mediator (Park et

		al. 1999).
Escherichia coli	Glucose, Sucrose	Mediator such as Methylene blue (Schroder et al. 2003).
Enterobacter and *cloacae*	Acetate, Sucrose	Mediator-less MFC (Masih et al. 2012a).
Geobacter metallireducens	Acetate	Mediator-less MFC (Min et al. 2005).
Geobacter sulfureducens	Acetate	Mediator-less MFC (Bond et al. 2002).
Shewanella putrefaciens	Acetate, glucose	Mediator-less MFC (Kim et al. 1999) but incorporating an electron mediator like Mn (IV) or NR into anode enhanced the electricity production (Park and Zeikus et al. 2002).
Shewanella oneidensis	Lactate	Anthraquinone -2,6-disulfonate as mediator (Ringeisen et al. 2002).
Lactobacillus plantarum	Glucose	Ferric chelate complex as mediator (Vega et al. 1987).
Desulfovibrio desulfuricans	Sucrose	Sulphate mediator (Ieropoulos et al. 2005).

5.4 Generation of Electricity Utilized Wastewater Treatment

Wastewater is a new concept of promises to high energy requirement of conventional sewage treatment system in demand for production of electricity, due to removing ammonia from wastewater to utilized clean water. This will be cost-effective and require less energy for its efficient operation for generating electricity. Wastewater effluent from industrial, municipal and other sources acts as a major source for energy harvesting and separately proving to be a suitable substrate toward bio-remediation. These are different sources of wastewater management for the electricity generation used in MFCs which included domestic wastewater (Liu et al. 2005), Swine wastewater (Heilmann et al. 2006), Meat packing wastewater (Kim et al. 2004), Food processing wastewater (Oh et al. 2005), Hydrogen fermentation reactor effluent (Feng et al. 2008) and brewery wastewater (Li et al. 2013). While other compared to pure substrates, complex organic substrates such as wastewater wastage from different sources may generate potential problems interfering with electricity generation such as toxicity due to high concentration of ammonia and due to volatile acid production during the hydrolysis and substrate fermentation (Furukawa et al. 2006).

VI. ACHIEVABLE ELECTRICAL OUTPUTS OF BPVS

The bio-photovoltaic device is biological solar cells that generate electricity used by moss, algae and plant. This device can be made by alga material by placing algae inside two electrodes-containing chamber separated by proton exchange membrane that only allows proton pass through an external circuit (Li et al. 2013). The BPVs device for generates electricity is achieved by various type of material to be used as stainless steel connector, steel clips and copper wire connect to at anode other the cathode in chamber. The obtained of voltage is measured, pressure and force of electricity, whereas amperage measured the amount of electricity finally produced green electricity to be stored in power battery for long-time duration. Power and polarization curve was obtaining of BPVs device for analysis the cell voltage (V) under pseudo-steady state condition. The current was calculated according to Ohm' law as a general equation follows ($I = V/R_{ext}$) and power (P) was calculated as shown in the following equation ($P = V^2/ R_{ext}$). Power curves are determined by varied the external load with BPVs device (Bombelli et al. 2013). The achievable electrical outputs for optimised light-dependent bio-electrochemical system (BESs) have been observed, in photoMFCs systems (Bombelli et al. 2016). Malik et al. (2009) according to estimate the maximum electricity generates for mixed culture-based complex for photoMFCs to 20, 000 mA m^{-2}, and based on the flow of O_2 to cathode. They have analyzed cell voltage at peak power (150 mV) the maximum electricity produced in system to 3000 mW m^{-2}. Strik et al. (2011) observed the electricity produced using plant-based complex as C_3 plant with photosynthetic efficiency close to maximum (5%) and which transport the majority of fixed carbon to the rhizosphere (70%), and also energy recovery of 60% from these carbon compounds through photo-MFCs system. Estimate constant solar radiation at ground level (SRG) of 150 000 mW m^{-2} as the electrical energy input and current outputs of 3200 mW m^{-2} achieved.

Similarity, On the basis of Bryo-MFCs device was operated with *P. patens* totally different parameter like current out-put ($51.4\pm 7.0\mu A\ m^{-2}$), charge accumulation ($18.2\pm 2.3\ Cm^{-2}$) and power out-put ($2.6\pm 0.6\ \mu W\ m^{-2}$). This finding is reliable with published studies where vascular plants and algae have been used to generate electrical power in plant-MFCs and BPVs, respectively (Strik et al. 2011; Kaku et al. 2008). VP-BPVs device has been used to *O. sativa* and *E. glabrescent* was characterized by diurnal oscillations with clear fluctuations between the trough and the peak values (Bombelli et al. 2013). These system are averages of the trough and peak values were 75.1± 6.8 and126.3± 18.7 mV, severally, representing a ~70 % to extend from average trough to average peak. The moss FM is the first example of bryo-MFCs able to run on commercial radio powered by a battery that was exclusively charged by Moss. The bryo-MFCs are few characters observed *P. patens* and another environmental sample of moss can be used to in a MFCs set-up to generate electrical output in combination with micro-organisms. They observed comparisons of near-sterile bryo-MFCs confirmed the importance of microbial population for transduction of the electrogenic activity and they are used to power a commercial radio or an environmental sensor (Bombelli et al. 2016). The biological photovoltaic device is used in a different set of application than traditional solar cell and may be some fundamentally of new approaches for producing green electricity.

CONCLUSION AND FUTURE PROSPECTS

The biological material can be used as electricity in BPVs system. But natural wastes for power generation are normally non-hazardous, can be disposed easily and low-cost. The bio-photovoltaic cell system built and operated at natural light or electronic wire, ambient temperature and neutral pH. The different photosynthetic activity of organisms is to be used for utilization in BPVs system. Most of the researchers work and major breakthrough is required for understanding the proof of principle design and mechanism of photosynthetic activity solar cells for harness light energy and convert to electricity. The main objective of this paper focus on the production of electricity using by BPVs system act as a sustainable source of electrical energy minimizing the exploitation of fossil fuels result in production of green electricity. Therefore, BPVs has demonstrated to be an efficient way of controlling environmental pollutants and combination may enhance stability, efficiencies and sustainability.

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