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Electricity Generation & Other Applications using Microbial Fuel Cell

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ABSTRACT

A Microbial Fuel Cell is a device where the bacteria can grow on one electrode, they breakdown organic matter and release electrons from it. The bacteria can do this by keeping them separate from the oxygen, and when they release those electrons it creates a potential between the two electrodes of about half a volt and voltage times current is power, and that is how power is generated from it. But MFCs are not restricted to generating power they can also be used to produce biofuels. Process can also be used to extract hydrogen and methane using appropriate membrane between the anode and cathode. Given paper explores this spectrum of scenarios and speculates the possibility of generating power using the Himalayan top soil.

***Keywords*:** power, microbial fuel cell, soil, organics, Electricity Generation

1. INTRODUCTION

Fuel cells are considered environment-benign technology providing solutions to a range of environmental challenges, such as harmful levels of local pollutants, in addition to providing economic benefits due to their high efficiency. Because of their potential to reduce the environmental impact and geopolitical consequence of the use of fossil fuels, fuel cells have emerged as potential alternatives to combustion engines. Fossil fuel reserves are limited

and it has been predicted that the production of fossil fuels will peak around 2020 and then decline [1]. To meet the demand of food and energy of the ever increasing population and to protect the environment from the ill effects of fossil fuel use [2], research and development in the area of fuel cells need to be significant. The reported estimate of worldwide environmental damage is around $5 trillion annually [3]. Fuel cells are electrochemical device which converts chemical energy from the fuel and oxidant into electricity directly; process generates heat and has high efficiency. Electrochemical processes in fuel cells are not generated by Carnot's cycle therefore the operation is simple and more efficient compared with internal combustion (IC) engine. In this literature we have focused on a special kind of fuel cell known as a microbial fuel cell or MFC.

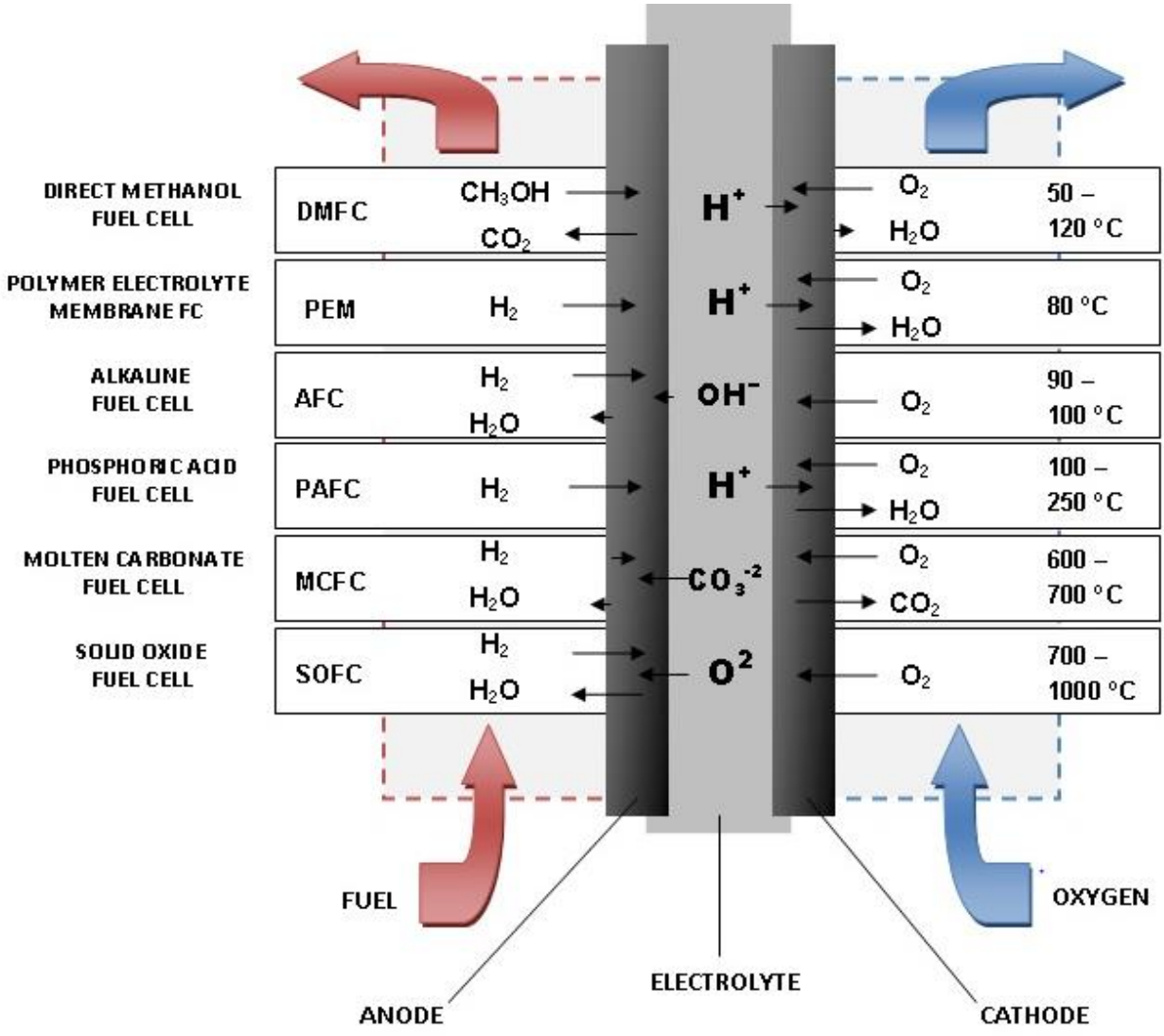

Figure 1. Different types of Fuel Cells; each fuel cell type has its own unique chemistry, such as different operating temperatures, catalysts, and electrolytes. Image adapted from FuelCells.org [42].

2. PERFORMANCE CHARACTERISTICS OF MICROBIAL FUEL CELLS

A study conducted by Prof. X. Meng at Steven Institute of Technology [4] in New Jersey, USA observed the relationship between organic matter and electrical capacity of MFC fuelled by the sample. High percentage of organic matter in sample resulted in higher electricity production of MFCs powered by that sample. Upper thermal limit investigated in the study was 40 °C and lower thermal limit investigated was -5 °C, and how this can be used in environmental sensors. Electricity production decreased linearly over a period of ten days. Samples used were Benthic mud, Top soil and marshes. Temperature profile varied between 0 °C, 40 °C and room temperature. Electricity capacity was greatest at 0 °C with the benthic mud samples of dimension 3.5cm×3.5cm×4.6cm. The interesting thing about this finding was that zero degree performance was superior to both room temperature and 40 °C marsh samples which appeared to have high organic content.

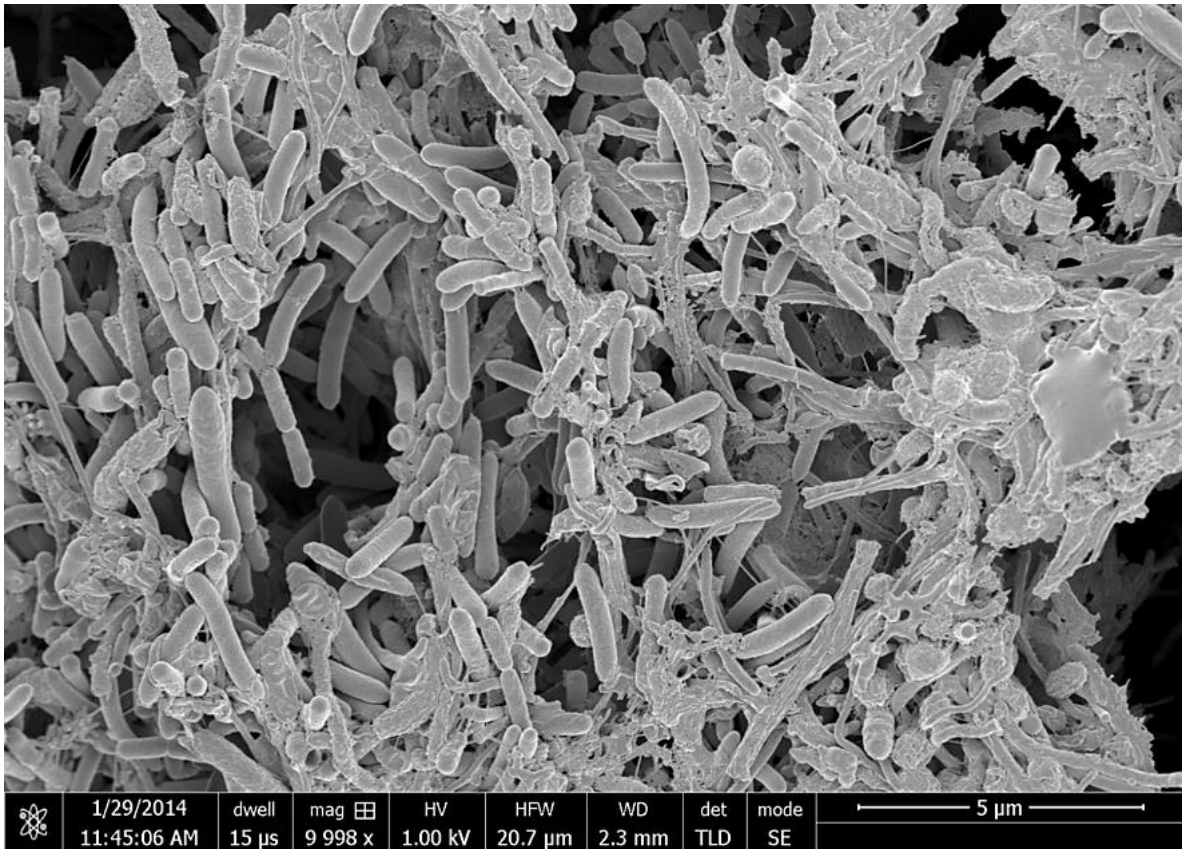

Figure 2. Scanning electron microscopy image showing biofilm formation on the anode surface of the pilot-scale MFC after 6 months operation, adopted from the work of Goryanin (2013) [39].

Electricity production from MFC can be increased by selecting the right condition of temperature, sample type and size. The study confirms high organic content in sample leads to great electricity production but the temperature profiles stated are not the exact thermal limits. Use of an apparatus with gradual change of temperature can provide a better understanding of these limits; also from the experiments it is not clear that thermal limits differences for MFC

samples as in how they vary with sample size and variety, and the type of bacteria that allowed this method is also not clear.

2. 1. Voltage generation characteristics

A study by Pranab Barua et al. [5] demonstrated that the first order derivative of voltage generated from an MFC with respect to time is a negative constant. Hence change in voltage with respect to time is independent of time. Also the generated voltage decreased linearly with time. The key finding of this work has been the mixture of bio-wastes used that resulted in high extractable current than any single component. Also when a component results in high voltage production, it ends up reducing cell life. The study used specific quantities of cow dung, drain water, rice washing water individually and combined with slurry. Cell life decreased after addition of slurry but increased after adding vermicompost.

The study while showing the combination of bio-wastes and its usage with MFCs was unable to highlight any significant feature as in what combination of bio-wastes should be used and at what interval it should be replenished.

2. 2. Anaerobic Digestion applications

Anaerobic digestion goes on inside the MFC. Process is typically applied in sewage sludge treatment due to its advantages over aerobic systems, such as lower energy consumption, smaller amounts of solids generated, lower nutrient requirement and potential energy recovery from the produced biogas. Sewage sludge is stabilized during anaerobic digestion by converting most organic matter into biogas [6].

2. 3. Microbial Fermentation

Microbiological fermentation processes proceed directly in the anodic compartment of the fuel cell, supplying the anode with the fermentation products. In this case, the operational conditions in the anodic compartment are governed by the biological system, and therefore they are significantly different from those in conventional fuel cells. This would be a real microbial fuel cell which is not a simple combination of a bioreactor with a conventional fuel cell. This configuration is also often based on the biological production of hydrogen gas, but the electrochemical oxidation of H2 is performed in presence of the biological components under mild conditions.

It has been shown that the performance of a microbial fuel cell depends heavily on the primary substrate used in the process of fermentation. The metabolic process in the bacteria is very complex. It involves many enzymes. It may proceed by many different routes. It has been shown that a mixture of nutritional substrates can result even in higher extractable current than any single component [23].

Microbial fuel cells require continuous fermentation of living cells performing numerous physiological processes thus dictating stringent working conditions. In order to overcome this constraint, redox enzymes responsible for the desired processes may be separated and purified from living organisms and applied as biocatalysts in microbial fuel cells; these were key findings from a study by Ashton et al. (1984) and Yahiro et al. (1964) [24,25]. Enzymes are expensive chemicals. Special ways for their utilization still remains to be established. A study by Willner et al. (2001) has suggested methods to electrically contact redox enzymes and electrode supports [26].

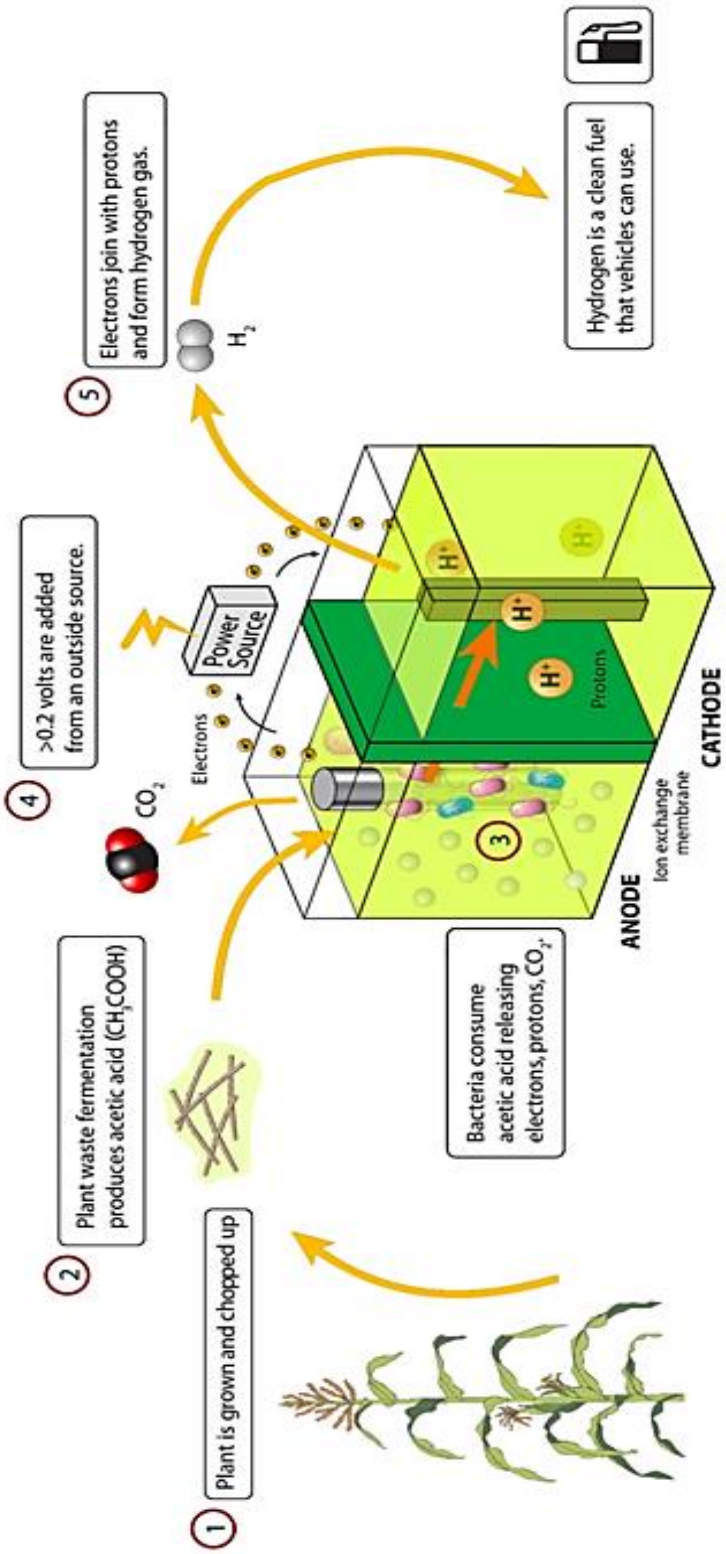

Figure 3. As a protagonist in the development of renewable energy, microorganisms play a significant role in sustainable energy exploitation in which biomass generation is of promising future development. Image adapted from Hust China[40].

2. 4. Production of electrochemically active substances

Microorganisms have the ability to produce electrochemically active substances that may be either the metabolic intermediaries, or the final products of anaerobic respiration. For the purpose of energy generation, these fuel substances can be produced in one place and transported to a microbial fuel cell to be used as fuel. The biocatalytic microbial reactor produces the microbial fuel. The biological part of the device is however not directly integrated with the electrochemical part. It allows the electrochemical part to operate under conditions that are not compatible with the biological part of the device.

2. 5. Artificial Electron Transfer

The application of artificial electron transfer relays that can send electrons between the microbial biocatalytic system and the electrode back and forth. The mediator molecules take electrons from the biological electron transport chain of the microorganisms and transport them to the anode of the microbial fuel cell. In this case, the biocatalytic process performed in the microorganisms becomes different from the natural one, because the electron flow goes to the anode and not to a natural acceptor of electrons. Since the natural electron acceptor is expectedly more efficient, it can compete with the desired scheme, and hence it is usually removed from the system. In most of the cases, the microbiological system operates under anaerobic conditions, allowing electron transfer to the artificial electron relays and, finally to the anode.

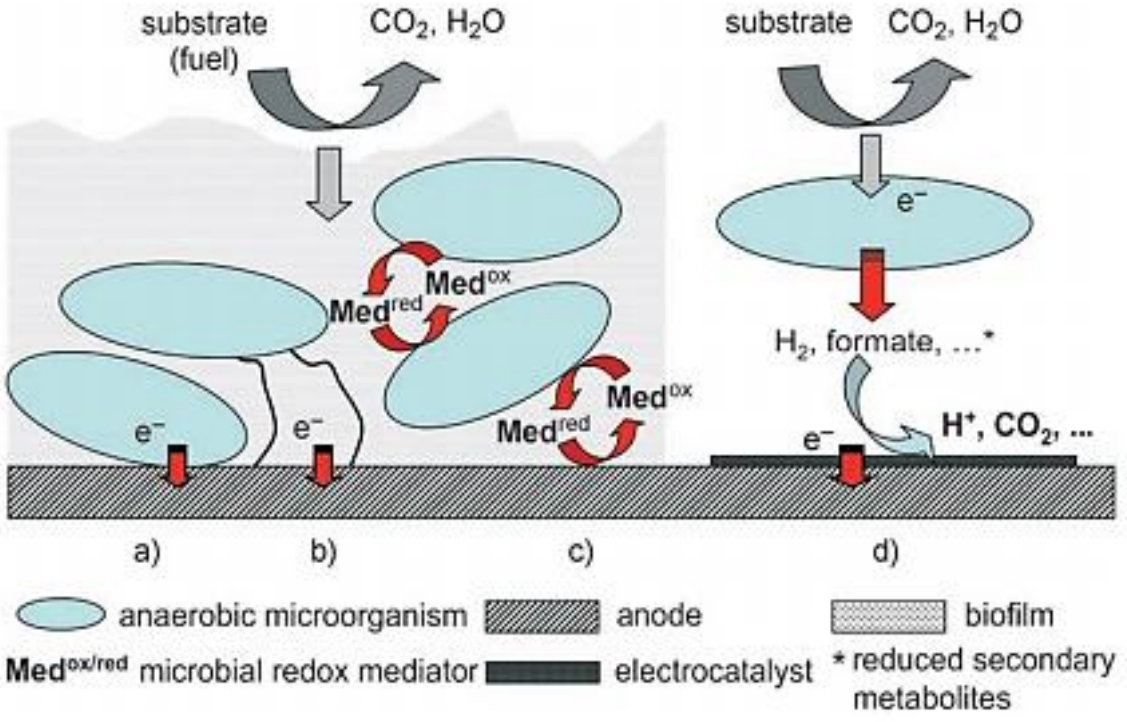

Figure 4. Identified electron-transfer mechanisms in MFCs. Electron transfer via a) cell-membrane-bound cytochromes, b) electrically conductive pili (nanowires), c) microbial redox mediators, and d) oxidation of reduced secondary metabolites; A study by M. Rosenbaum (2006) [38].

Eugene et al. (2003) reported that various bacteria and algae have been found to be active in hydrogen production under anaerobic conditions [11]. Suzuki and Karube (2003) found that the most effective hydrogen production is observed upon fermentation of glucose in the presence of Clostridium butyricum [12]. This conversion of carbohydrate to hydrogen is achieved by a multienzyme system. Immobilization of the hydrogen-producing bacteria, Clostridium butyricum is very important because it stabilizes the unstable hydrogenase system. In order to stabilize the biocatalytic performance, bacteria were in fact introduced into agar gel by Karube et al. (1981) and Suzuki et al. (1980) [13,14] and in filter paper [15] by Isoda et al. (1983).

Many different organic and organometallic compounds have been tested in combination with bacteria to test the efficiency of mediated electron transfer from the internal bacterial metabolites to the anode of the microbial fuel cells. Thionine has been used extensively as a mediator of electron transport from Escherichia coli as shown from the studies by Roller (1984) and Benneto (1983) [18,19].

Ferric complexes have also been successfully used for oxidizing glucose [20] as reported by Vega (1987). Since thionine has frequently been used as a mediator in microbial fuel cells, mono and disulfonated derivatives of thionine have been applied to determine the effect of hydrophilic substituents on the mediation of electron transfer [21] as shown by Lithgow (1986). Engineering of the electrochemical cell provides a means of enhancing the electrical contact between a biocatalytic system and an anode, and hence to improve the cell output. Kramer (1989) showed that the interfacial contact has been found to increase while using a three dimensional packed bed anode [22].

2. 6. Biocatalytic Activities

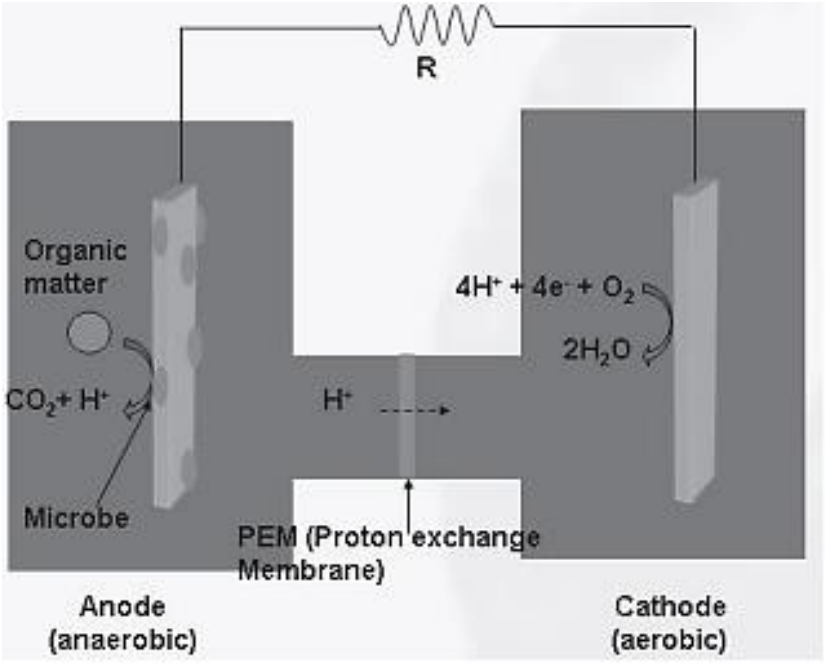

Figure 5. Microbes remove the electrons from organic matter and transfer them to the anode in the anaerobic chamber. The electrons move across the resistor to the cathode where they combine with protons, and oxygen to form water; adapted from [32].

Microbial fuel cells use biocatalysts for the conversion of chemical energy to electrical energy [7-9] as confirmed by the studies of Sisler (1971), Turner et al. (1982) and Palmore (1984). As most organic substrates undergo combustion with the release of energy, the biocatalyzed oxidation of organic substances, by oxygen or other oxidizers, provides a means for the conversion of chemical to electrical energy. Biocatalysts take part in the process of producing electricity in either of the two following ways: the biocatalysts can generate the fuel substrates for the cell by biocatalytic transformations or metabolic processes, or the biocatalysts may participate in the electron transfer chain between the fuel substrates and the electrode surfaces. A variety of electron mediators are used for the electrical contacting of the biocatalyst and the electrode [10] as shown by Barlett (1991).

2. 6. Reduced Sulfur content

There are many microorganisms producing metabolically reduced sulfur containing compounds such as sulfides and sulfites. Sulfate reducing bacteria form a specialized group of anaerobic microbes that use sulfate as a terminal electron acceptor for their respiration. These microorganisms yield S_2- while using a substrate, lactate for example, as a source of electrons. This microbiological oxidation of lactate with the formation of sulfide has also been used to drive an anodic process in microbial fuel cells [16,17]. Accumulation of sulfides in the medium results in the inhibition of the metabolic bacteria because they interact with iron containing proteins, blocking the electron transport systems. To prevent the toxic effect of H_2S, the anode should effectively oxidize it. However, many metallic electrodes are corrupted by sulfides because of their strong and irreversible adsorption. Therefore, porous graphite electrodes have also been used [16,17] for the purpose.

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2. 7. Biocatalytic applications

Conventional oxygen reducing cathodes used in fuel cells are usually not compatible with biocatalytic anodes since high temperature and pressure are applied for their operation. Thus, biocatalytic reductive processes at the cathode should be considered as a strategy to design all biomaterial-based functional fuel cells [11]. It has been reported that bioelectrocatalyzed reduction of H_2O_2 has been accomplished in presence of various peroxidases such as horseradish peroxidase [27].

The biocatalytic reduction of oxidizers in nonaqueous solutions immiscible with water is important because it can be coupled to biocatalytic oxidative processes through liquid liquid interfaces. Some enzymes [28] as shown by Klibanov (1989), particularly peroxidases [27] as studied by Ruzgas et al. (1996) can function in non-aqueous solutions. Horseradish peroxidase electrodes have been tested for biocatalytic reduction of organic peroxides in non-aqueous solvents [29] by Li et al. (1998).

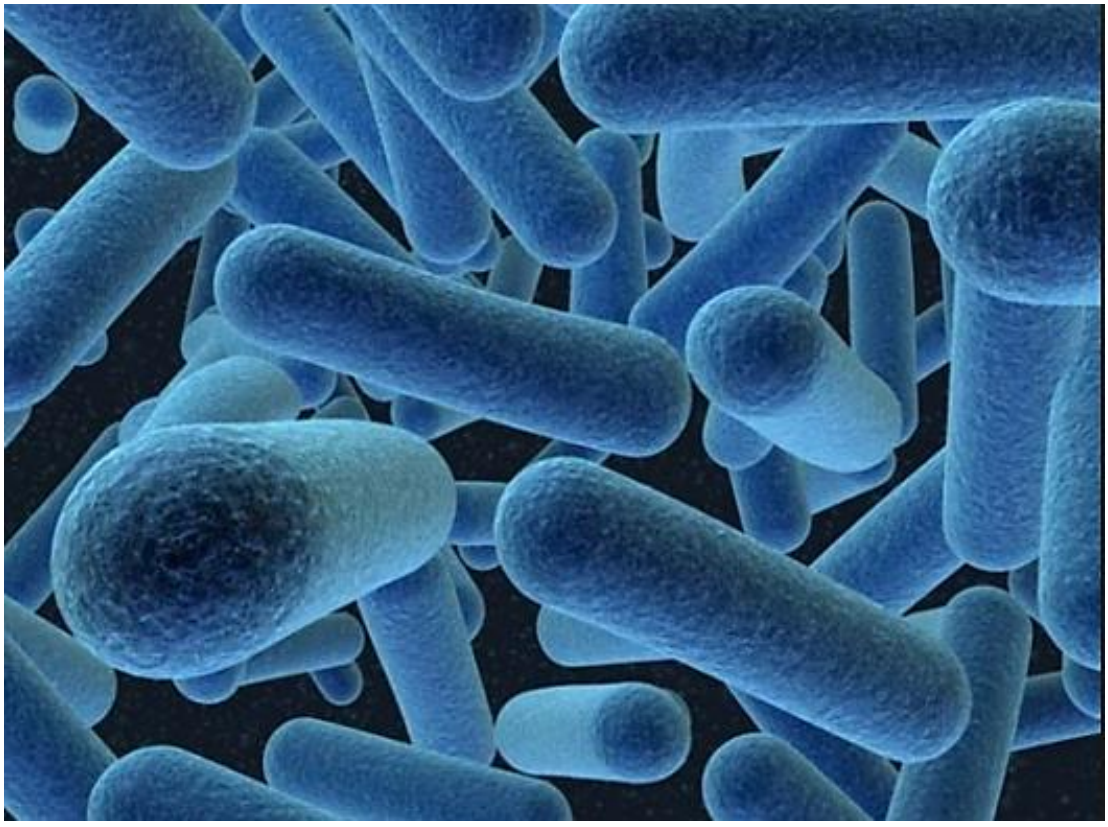

Figure 6. Bacillus stratosphericu, bacteria under a powerful microscope, a biofilm or slime coats the carbon electrodes of the MFC and as the bacteria feed, they produce electrons, Technology update [41].

The biocatalytic activity of enzymes [30], however, is usually lower in organic solvents than in water. Biocatalytic systems composed of enzymes and their respective electron transfer mediators such as bilirubin oxidase [31] as reported by Tsujimura et al. (2001), or fungal lactase [32] as reported by Tayhas (1999) are able to biocatalyze the electroreduction of O_2 to H_2O significantly decreasing the potential. These systems, however, are composed of dissolved enzymes and mediators operating through a diffusion path that is not acceptable for technological applications.

The microbial fuel cell voltage and current outputs are oxygen insensitive. This oxygen insensitivity of the bioelectrocatalytic process at the anode originates from the effective electrical contact of the surface with the electrode support, as a result of its alignment [33,34], this was confirmed by both Willner (1996) and Katz (1999). The stability of the microbial fuel cell was examined at an optimal loading resistance as a function of time [35]. The power decreases by about 50% after 3 hours of cell operation. This loss could originate from depletion of the fuel substrate, leakage of the fuel or the oxidizer into the wrong compartment, or degradation of the biocatalysts. Since the cell voltage appears to be stable, the current produced also decreases by the same factor. Recharging the cell with the fuel substrate and oxidizer could compensate for this component of the decrease in the current output.

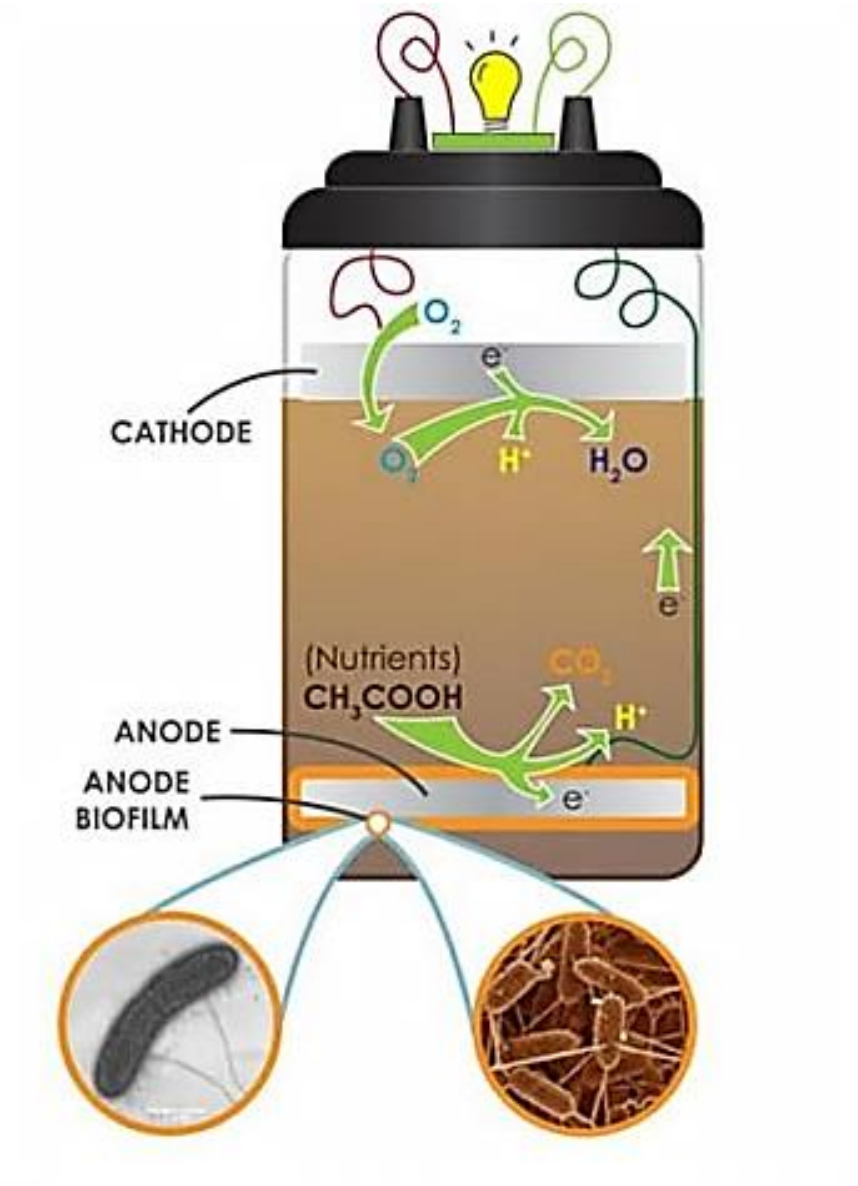

Figure 7. This diagram shows the reactions taking place in a microbial fuel cell (or MFC) that make it generate electricity; Adapted from Wikimedia Commons, 2010, MFCGuy2010.

Charge transfer processes across the interface between two immiscible electrolyte solutions can provide an additional potential difference between cathodic and anodic reactions due to the potential difference at the liquid-liquid interface. Many different interfacial liquid-liquid systems have been studied using numerous experimental approaches [36]. The reduction of peroxide in dichloromethane, and the oxidation of glucose in aqueous solution, bioelectrocatalyzed by the electrode, enables us to design a liquid-liquid interface microbial fuel cell using peroxide and glucose as cathodic and anodic substrates respectively [37].

3. USE OF HIMALAYAN TOP SOIL TO CHECK MICROBE ACTIVITY USING MFCS

It is proposed to test MFC on Himalayan soils of Uttarakhand. District Dehradun is situated in NW corner of Uttarakhand state and extends from N Latitude 29°58’ to 31°02’30" and E Longitude 77°34’45” to 78°18’30”. It falls in Survey of India Toposheets Nos. 53E, F, G, J and K. The district is bounded by Uttarkashi district on the north, Tehri Garhwal and Pauri Garhwal districts on the east and Saharnpur district (UP) on the south. Its western boundary adjoins Sirmour district of Himachal Pradesh separated by Rivers Tons and Yamuna. District Dehradun is drained by Ganga, Yamuna and their tributaries. The two basins are separated by a ridge starting from Mussoorie and passing through Dehradun.

3. 1. Soil Profile

Soil on the mountains is moderately deep, well-drained, thermic coarse loamy soils on steep slopes, strong, stoniness, associated with shallow excessively drained and loamy. Soil on the upper plains are deep, well-drained, coarse loamy cover, fragmental soils on heavy gentle slope with loamy surface and slight erosion; associated with excessively drained soils with loamy surface and slight to moderate erosion. Soil on the lower plain are deep, well-drained, coarse loamy cover over fragmental soils on nearly level plains with loamy surface; associated with deep, well drained, fine loamy soil with loamy surface.

4. CONCLUSION

The concept of MFCs can be used in places lacking proper sanitation and electricity, the process of generating electricity in these can also purify water. There is still significant research to be done with MFCs and with advancement in its work and scope it can be speculated to be an energy source particularly in the rural sector of third world countries. As climate change affects life on earth reliance on renewable energy sources become increasingly important, we develop ways to solve the energy conversion crisis. Soaring oil prices and forward investments of large corporations pushed, in recent years, some of these technologies to cutting-edge development and to the brink of commercial viability.

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