# Utilization of Electroactive Bacteria in Microbial Fuel Cells for Bioremediation and Their Applications in Natural Ecosystems

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## Abstract

Many microorganisms found in the natural world have evolved systems for transferring electrons away from the cell surface. This electron transfer enables these bacteria to be used in bio-electrochemical systems like microbial fuel cells (MFCs) and microbial electrosynthesis (MES). Electroactive bacteria (EAB) are distinguished in these applications by their ability to transport electrons from the microbial cell to an electrode, or vice versa, in place of their natural redox partner. Overall, the use of electroactive organisms in BES opens up the possibility of developing efficient and sustainable processes for producing energy, bulk, and microcompounds. In this article, we compare and contrast the key microbiological characteristics of several EABs.

**Keywords:** micrrobial fuel cell, microbial electrosynthesis (MES), electroactive bacteria.

## Introduction

Bioelectrochemical systems (BES) are systems that utilize microorganisms capable of transporting electrons, such as microbial fuel cells (MFCs) and microbial electrosynthesis (MES). Electroactive bacteria (EAB) play a crucial role in these systems, transferring electrons from their cells to electrodes or vice versa. The use of EAB in BES offers potential for creating efficient energy and bulk chemical production systems that are both environmentally friendly and effective.

### Electroactive Bacteria

Microorganisms that are prevalent in the natural environment and have the ability to generate energy through a wide variety of metabolic pathways are classified as Electroactive bacteria. The germs in question belong to the category of bacteria that produce electricity. M.C. Potter, who was a professor of botany at Durham University at the time, was the first person to propose the idea that microbes could be utilized for the purpose of producing energy [1]. Despite the fact that microorganisms have only recently been used for practical purposes, this continues to happen. He produced a voltage of 0.3 to 0.5 V after immersing a platinum electrode in a solution containing a bacterial and yeast suspension as well as glucose. He discovered that this solution generates the voltage. The experiment produced the results described above.

Electromicrobiology is a relatively new branch of the scientific community that focuses on the exploration of activities that involve certain groups of microorganisms in the developing field of bioelectronics [3]. The recommended method for achieving this goal is to conduct an analysis of the electron exchange that occurs between microorganisms and external electrical equipment. The pioneering experiments conducted while laying the groundwork for the nascent field of electromicrobiology established the framework for the field.

## Microbial Fuel Cells

Microbial fuel cells, also known as MFCs, are a renewable energy source that can generate bioelectricity from waste. There are several types of microbial fuel cells (Figure 1). As environmental concerns and the depletion of fossil fuels grow, microfluidic cells (MFCs) become increasingly important for the generation of environmentally sustainable bioenergy. MFCs use biofilms and electroactive bacteria (EAB) to convert organic molecules into energy. Extremophiles can tolerate high temperatures and pressures, making them a potentially useful technology for MFCs.  However, MFCs face significant challenges, including technological limitations and insufficient power generation. Despite these challenges, MFCs may be considered a viable solution for the generation of renewable energy.

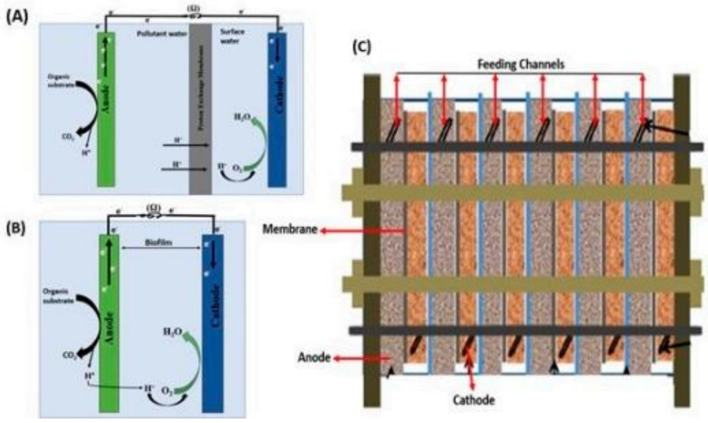


**Figure 1.** Microbial Fuel Cell. A. Double Chamber; B. Single Chamber; C. Stacked

## Bioremediation

Growing world population, carbon dioxide emissions, and excessive consumption of fossil fuels have led to environmental degradation that needs to be addressed urgently on a priority basis worldwide. Most of this environmental pollution is caused by anthropogenic activities such as cutting down of trees, rapid urbanisation, construction and so on. Due to their high levels of toxicity, a wide range of pollutants, such as heavy metals, polychlorinated compounds, and plastic, remain a super threat to the environment. As per the recent advancements in this regard, bioremediation has come up as one of the most promising and sustainable solutions to counter the increasing number of environmental pollutants. Bioremediation involves the application of biotic factors such as microorganisms and plants for the removal of toxic, hazardous pollutants from the soil. This approach to cleansing the degraded environment is both feasible and appealing. The initial step involved in bioremediation is biodegradation, where organic and inorganic matter is degraded by the action of microbes such as bacteria and fungi. The harmful products of biodegradation are converted into less toxic forms, either chemically or physically, by the process of elimination. The end products received at the end of these processes are either immobilised in less toxic forms or vaporized.

Depending on the site of remediation, bioremediation can be in-situ which is the treatment of a contaminated environment at its native place without excavation, or ex-situ which involves the removal of waste to an isolated place followed by its treatment with microbes. Water pollution caused by industrial waste discharge into sewage systems, as well as soil pollution caused by excessive mining and other related activities, are two key targeted processes that can be treated with bioremediation.

Bioremediation basically involves use of certain aerobic and anaerobic type of bacteria and fungi for wastewater treatment. Certain groups of bacteria, such as Archaea, are well known for bioremediation, along with other advantages such as promoting plant growth, soil restoration, and recycling. Another advantage associated with using bacteria for waste treatment is that bacteria are found growing in all types of environments, ranging from extreme heat, such as volcanic depths, to saline or acidic environments.

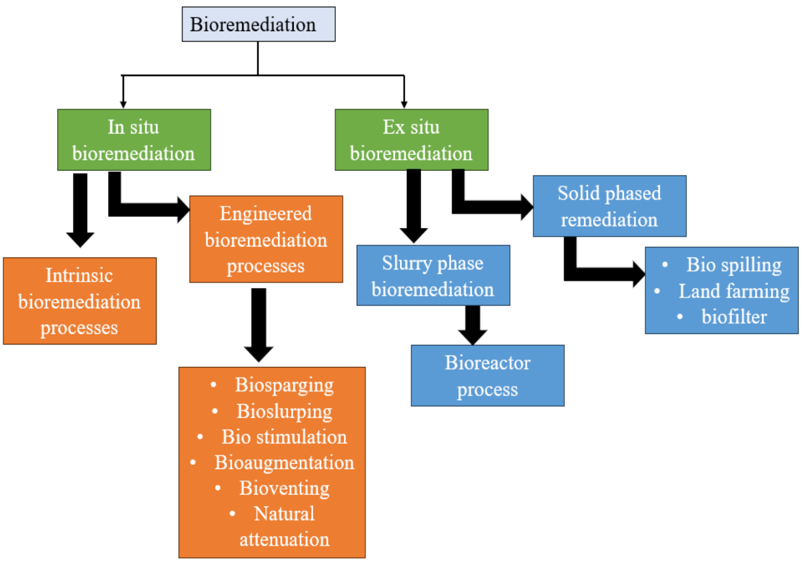


Figure 2: Different techniques Bioremediation.

The enzymes secreted by these microbes are able to degrade complex hydrocarbons present in pollutants such as petroleum products, oil spills, and benzene into simpler forms. Some of the most commonly used microbes for bioremediation include *Pseudomonas, Flavobacterium, Nitrosomas, etc*.One of the most important principles to follow is the process of degrading pollutants and transforming them into less harmful forms. There are two groups of variables that can be considered when determining the rate of deterioration. These are biotic circumstances and abiotic factors. When performing the calculation, both of these criteria are taken into consideration individually. As far as bioremediation is concerned, there are now a number of different techniques that are utilized (Figure 2).

There has been a concerning increase in the amount of pollution that has been released into the environment on account of human activities throughout the course of the several decades that have passed. This increase has occurred over the past several decades. Examples that fall under this category include the exponential expansion of the human population, farming techniques that are careless, city planning that is unregulated, the cutting down of forests, rapid industrialization, and the reckless exploitation of energy resources.

There are many different types of pollutants that are harmful to both the environment and public health. Some examples of these pollutants are chemical fertilizers, heavy metals, nuclear waste, herbicides, insecticides, greenhouse gases, hydrocarbons, and pesticides. Among the other examples are nuclear waste and trash from industrial processes. Due to the fact that they are contaminants, these pollutants are among those that are considered to be among those that do not only threaten the health of the general population but also the environment. Over the next few decades, there is likely to be a significant rise in the number of locations that are home to hazardous waste, according to the perspectives of many experts.

The number of locations that are responsible for the disposal of hazardous waste has already reached thousands, and it is anticipated that this number will dramatically increase. For example, one of the most significant contributors to environmental contamination is the illegal dumping of commercial chemicals and other types of waste from industrial processes. Additional types of waste include waste that is produced throughout the manufacturing process. The previous approaches to site cleanup comprised excavating the toxic soil and the transfer of the dirt to either a landfill or an incinerator. This was the procedure that was first utilized.

Not only were these therapies extremely expensive, but they also did not provide a solution that would be effective over a longer period of time. This was a significant limitation of these types of treatments. Additional modern methods that involve a solution that is not only economical but also insufficient include soil venting and vapor extraction. Both of these processes are examples of modern processes. It is generally agreed that both of these approaches are considered to be quite modern.

The study uses a qualitative literature survey approach to investigate the problems of electrically active bacteria in fuel cells used for bioremediation. Sample selection is crucial in research design, and a simple random process was used to select cases. The study is based on secondary data collected from various sources, including internet websites, journals, books, and social media networks, ensuring a comprehensive understanding of the topic.

Electro microbiomes are a collection of naturally occurring microbial communities that are capable of forming biofilms and interacting electrically with one another as well as with their extracellular environment. Communities like these can be found in a wide variety of natural environments, and they are distinguished by their capacity to communicate with one another and to build biofilms. There is a wide variety of environments in which they can be found, such as soil, sediment, water digestive systems, corroding metal surfaces, and intestinal systems. Electroactive bacteria have been found abundantly in a variety of ecosystems, including freshwater environments, marshy terrain, brackish waterways, and marine sediment environments. In mangrove sediments, for instance, which are often subject to anoxic conditions and contain a significant amount of organic matter, these bacteria are able to convert organic matter into carbon dioxide.

There is a limited amount of research on soil ecosystems, despite the fact that they have been extensively researched. On the other hand, research has been carried out on paddy soils, sweet potato roots, and angelica stems. There are five bacteria that are capable of transporting electrons outside of the cell, and the human gut is a place that generates an environment that is suitable for the development of bacteria that

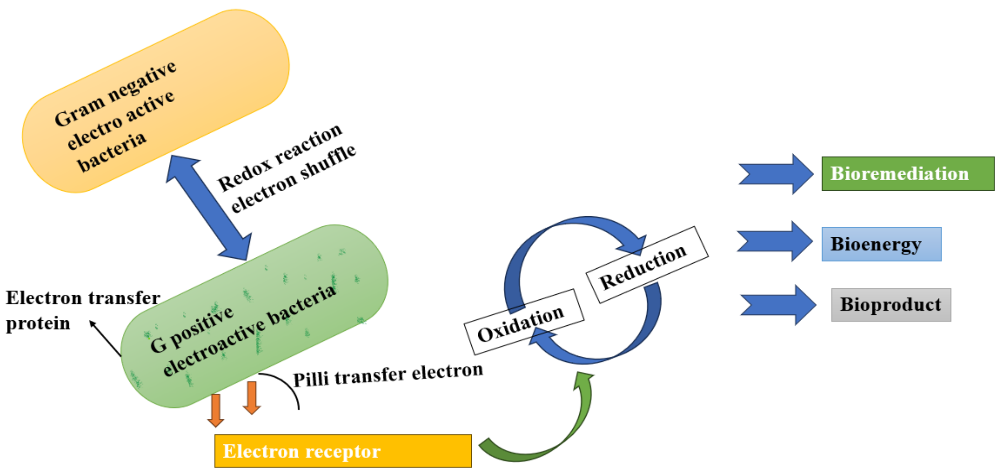


Figure 3: Development of bacteria capable of producing exoelectrogenic substances.

Due to the fact that these bacteria may be discovered in a wide variety of natural or man-made en[illegible]eful resource for gaining an understanding of the numerous ecosystems that they occupy.

Figure 3. Electron transfer in gram positive electroactive bacteria

**Electrogenic Bacteria in Microbial Fuel Cells**

The materials used to create an anode are crucial for energy generation. Carbon-based materials are preferred due to their high-performance capacity, low cost, biocompatibility, and strong electrical conductivity. Examples include felts, rods, brushes, and graphite fibre rods. Recent research has combined conductive materials with soybean and potato powder to create an anode that stimulates bio film growth. Natural materials like pomelo peel and carbon-containing neem wood have also been used, but most are not yet used in large-scale MFCs. The movement of electrons from the anode to the cathode produces electric power, denoted by P.

**Use of Microbial Fuel Cell for Removing Waste water Contaminant**

Waste water treatment and regeneration remain the most important and precious phenomena governing the development of under developed and developing countries like India, South African nations, etc. Conventionally used waste water treatment methods use high energy and machinery, as well as chemical treatments such as chlorine. These processes are not only time consuming but also involve a high cost. This clearly shows that these methods are not sustainable and cannot be utilised over the next few decades. Conventionally used methods of wastewater treatment encounter problems such as the elimination of unwanted sludge and other related particles.

This problem can be overcome by using microbial fuel cells, which are known to directly convert waste water into cleaner forms of energy such as electricity or other highly valued products. Bioelectrical systems such as these are known to convert chemical energy derived from organic sources or substrates into electricity. Indigenously present microbes are able to degrade waste products and release clean energy such as bioelectricity, bioethanol, etc.

The most accepted advantage associated with the use of microbial fuel cells (MFC) for pollutant degradation is that this process releases few carbon footprints, is eco-friendly, has a higher economic value, and generates less waste. The main principle behind this process is that toxic pollutants present in the waste water act as a substrate for the microbes, which in turn release highly valued products. A wide range of oxidation- reduction reactions are associated with these microbes and generate electrical energy that is eventually transferred and accepted at the electrode. The electron accepting compounds present at the terminal are known as terminal electron acceptors.

Municipal waste water, although having a lower biological oxygen demand and a low substrate for microbes, can be utilized under anaerobic conditions. Waste water generated from industries is rich in carbohydrates and nitrogenous wastes that act as ideal substrate for microbes. After effective treatment with MFC, the water leaving the electrode chamber is rich in elements such as nitrogen and phosphorus. Special, advanced types of biocathode chambers can be used to enhance the nutrient capacity of water. In addition, these technologies have the ability to minimize the amount of heavy metal. During the treatment process, certain compounds, such as antibiotics, are not completely eliminated from wastewater treatment facilities. Such substances include antibiotics. The research that was carried out by Zang and his colleagues was conducted with the intention of determining the pace at which nitroaromatic chloramphenicol decomposed in two chamber MFCs that were distributed by a negative ion exchange medium. The degradation of antibiotics in single chamber MFCs that had been kept for two months was the subject of an experiment that was carried out by Cheng and colleagues (Figure 4).

Nevertheless, th w the production of MFCs and b eration of power structures, the longevity of the MFC, and the preservation of efficiency are some of the obstacles that must be overcome. There was a full-scale MFC system test that was carried out by Liang and colleagues, and it was placed into operation for a duration of one year. They made use of a modularized MFC system that was designed to treat wastewater from municipal sources. The system had a capacity of one thousand liters and was designed to treat wastewater. Both of the electrodes in the system were made of granular activated carbon in order to maintain a high ratio of electrode surface area to reactor volume. This was done in order to ensure that the system was functioning properly.At rates ranging from 70 to 90 percent, the MFC system was able to remove carbon dioxide. Additionally, it was able to recover energy from municipal wastewater at a rate of 0.033 kWh per m3, and it was able to give power outputs that ranged from 0.42 to 3.64 W/m2. However, the documents that were provided did not include any information on the role of EAB in this initiative. This was extremely disappointing.

Figure 4. Various approaches for bioremediation of waste water

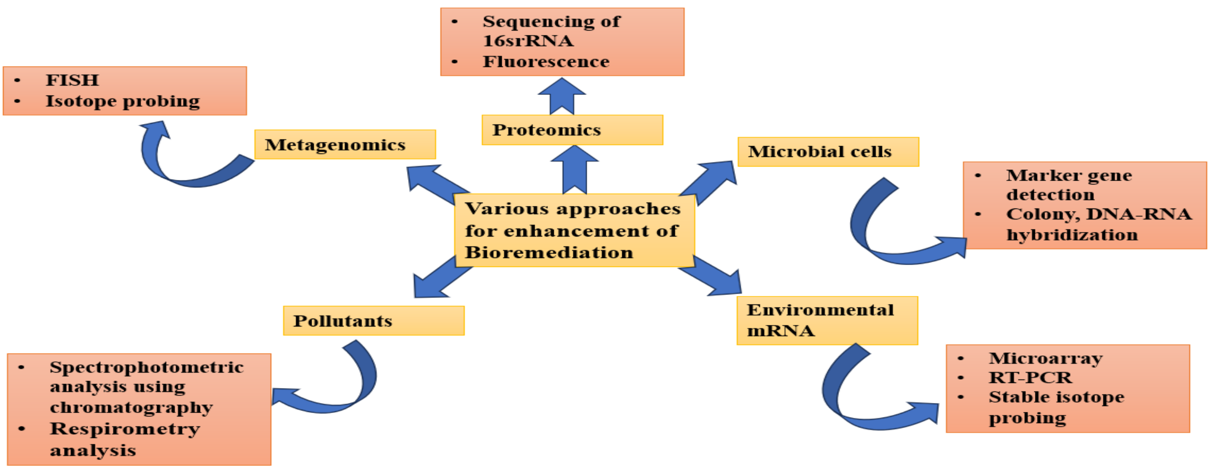


Figure 4: Degradation of antibiotics in single chamber MFCs.

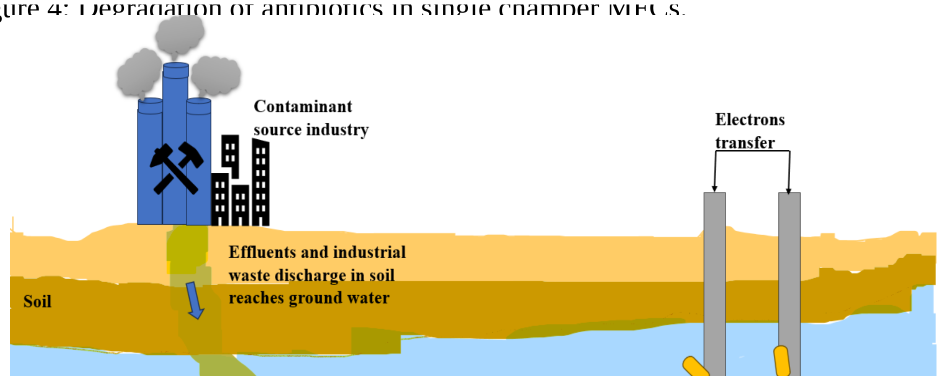

**Figure 5:** Performance of terrestrial MFC electroactive bacteria

**Multi-Functional Cells for Bioremediation of Heavy Metals and Persistent Organic Pollutants:** A promising strategy for eliminating both inorganic and organic contaminants from solid matrices, such as sediment and soil particles, is the utilization of terrestrial microbial fuel cells, often known as TMFCs. In comparison to other MFCs, these cells are superior in terms of their ability to generate energy because they make use of a more complex electrolyte, such as solid water or wastewater. It is possible for the performance of terrestrial MFC electroactive bacteria to be greatly improved by the incorporation of an external carbon source, such as glucose or compost (Figure 5).

The amount of water present is an essential limiting condition that must be met for this technology to function at its best. In the event that the moisture content of the soil is insufficient for electron transmission as a result of water evaporation, the generation of power will decrease. In order for TMFCs to be deployed for the purpose of recovering contaminated soils or sediments, the moisture content of the soil or sediment must be somewhat close to its maximal capacity for water retention.

According to the findings of a study that investigated the decomposition of hexachlorobenzene (HCB) in soil microbial fuel cells, TMFCs were able to obtain a maximum clearance rate of 71.15% in soils that had moisture levels that were greater than 51%. It is clear that the significance of this parameter is demonstrated by the fact that the elimination of HCB was greatly reduced when the soil water content was lower.

In order to lessen the amount of organic matter that is present in wastewater effluents, plant microbial fuel cells, also known as PMCs, are a form of microbial fuel cell that is meant to integrate with photosynthetic plant species. The ability of these devices to extract a greater quantity of organic waste and to generate electricity in a more constant manner is contributing to their growing appeal.

In conditions similar to those of rice plants, a sediment microbial fuel cell revealed a current generation capability of 26 mW/m2, which is seven times lower than the volume of energy produced by rice plants.

In addition, it was projected that the oxidation of rhizo deposits would generate up to 330 pounds per hectare. It was discovered through the utilization of a plant MFC that high molecular weight polycyclic aromatic hydrocarbons (PAHs) had the potential to degrade by 75-87 percent in polluted sediment because of the application of the plant MFC. It was discovered that the members of the genera *Geobacter, Desulfuromonas, Longilinea, and Bellilinea* were the ones that were found to be the most frequent in anode biofilms. It has been discovered that the facultative denitrifying bacteria known as *Denitratisoma* are capable of effectively digesting organic pollutants while simultaneously shielding *Geobacter* from oxygen.

**Conclusion**

Although the use of microbial fuel cells to combat and mitigate energy related environmental impacts is a sustainable approach, it has some shortcomings that need to be addressed over time. One major drawback is that no such protocol has been devised to date for large scale utilization of MFCs. Some of the key issues associated with this technology are listed below-

- Cost effective means of production, such as cheap but durable electrodes, need to be constructed.
- Practicing treatment of actual waste water.
- The outcomes of the experiment must be published in universally accepted journals.

The future focus of the studies must be on the development of large-scale industrial processes rather than laboratory practices. These hurdles can be overcome in the future after dedicated experiments and research in this field.

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