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Microbial Fuel Cell Possibilities on American Indian Tribal Lands

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Abstract

The purpose of this paper is to present a brief background of tribal reservations, the process of how Microbial Fuel Cells (MFCs) work, and the potential benefits of using MFCs on tribal reservations to convert waste water to energy as a means to sustainably generate electricity. There have been no known studies conducted on tribal lands that would be able to add to the estimated percentage of all renewable energy resources identified. Not only does MFC technology provide a compelling, innovative solution, it could also address better management of wastewater, using it as a form of energy generation. Using wastewater for clean energy generation could provide a viable addition to community infrastructure systems improvements.

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1.0 Introduction

In the United States, there are three types of reserved federal lands: military, public, and Indian. According to bia.gov, “A federal Indian reservation is an area of land reserved for a tribe or tribes under treaty or other agreement with the United States, executive order, or federal statute or administrative action as permanent tribal homelands, and where the federal government holds title to the land in trust on behalf of the tribe” [1]. American Indian land comprises approximately 2% of U.S. land, but contains an estimated 5% of all renewable energy resources [2].

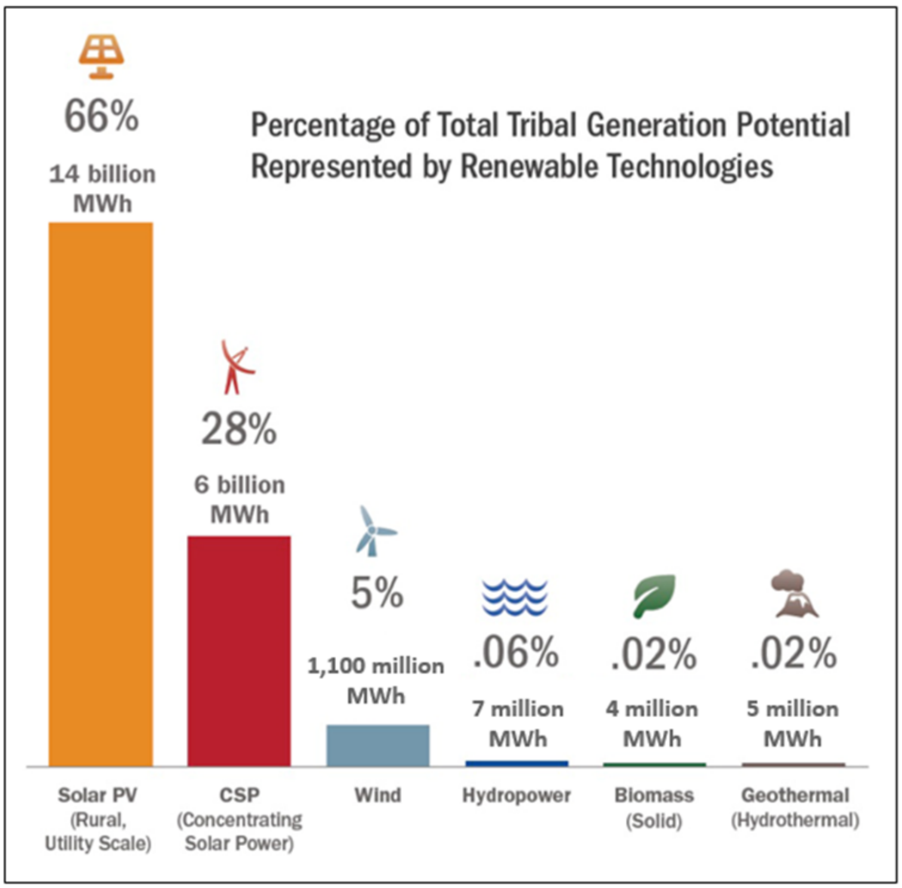

Figure 1. Percentage of Total Tribal Generation Potential on Tribal Lands [2]

As shown in Figure 1, the total technical potential on tribal lands for electricity generation from utility-scale rural solar resources is about 14 billion MWh, or 5.1% of total U.S. generation potential. The total technical potential on tribal lands for electricity generation from wind resources is about 1,100 million MWh, or about 3.4% of the total U.S. technical potential. The total technical potential on tribal lands for electricity generation from hydropower resources is about 7 million MWh, or about 2.9% of the total U.S. technical potential.

Approximately 2% of total U.S. electricity consumption goes towards moving and treating water and wastewater [3]. Although wastewater treatment systems reduce environmental impacts in the receiving water, the systems create other life cycle impacts primarily through energy consumption with greenhouse gas (GHG) emissions being associated with the chemicals and energy used in the treatment process [3]. Energy for wastewater treatment is likely to increase in the future due to increasing population, stricter discharge requirements, and aging infrastructure [4].

On the Standing Rock Indian Reservation, children are taught that all things are connected within the sacred circle of life and that we are all related. Traditionally, Lakota families orally passed on tribal beliefs and skills for survival to make sure the circle of life would continue. Their lives revolved around the buffalo, with its spirit being honored by the Lakota people, and every part of the buffalo was used for food, shelter, clothing and tools. The entire way of life for the Lakota people was in balance with nature and the people never took more than what nature could restore. Growing up with this in mind, the importance of taking care of our environment and water resources is understood; thinking sustainably today ensures a better tomorrow for future generations. With population growth, it is imperative to consider viable options for self-sustaining energy systems, such as the following tribal example provided through the Forest County Potawatomi Community's (FCPC) biogas facility project.

1.1 Case Study: Forest County Potawatomi Community

The FCPC obtained $2.6 million dollars in funding from the U.S. Department of Energy's (DOE) Community Renewable Energy Deployment program [5]. A two-megawatt renewable energy plant was built by the tribe [6]. The plant utilizes anaerobic digestion to convert food waste, which was supplied by Potawatomi Bingo Casino and local/regional food processing resources, into biogas used to power approximately 1,500 homes [5, 6]. Biogas is a biofuel produced from the anaerobic fermentation of carbohydrates in plant material or waste, such as food and wastewater, by bacteria and is primarily composed of methane, some carbon dioxide, and other various trace gases [7]. The methane captured can then be used as a fuel to generate electricity or provide heat to homes and buildings. While biogas plants significantly lower the greenhouse effects of methane emissions on the earth's atmosphere by entrapping the harmful gas, there is always the possibility of leaks and releases [8, 9]. Methane is a powerful, short-lived GHG and the main component in natural gas [9]. Compared to carbon dioxide, the leading contributor to manmade climate change, methane has twenty times the impact as a GHG [5, 9].

1.2 Why Waste to Energy?

Waste to energy is defined as "generating energy in the form of electricity and/or heat from the incineration of waste" [10]. There are two main processes used to convert waste into energy: thermal and non-thermal. Thermal processes include: incineration, gasification, pyrolysis, and plasma-based technologies. An example of a non-thermal processes is anaerobic digestion, as described in Section 1.1 Forest County Potawatomi Community Case Study. Waste is collected from the general population, transported to a treatment facility, processed and converted, and is finally outputted as a form of energy. Refer to Figure 2 for a general schematic of the waste to energy process.

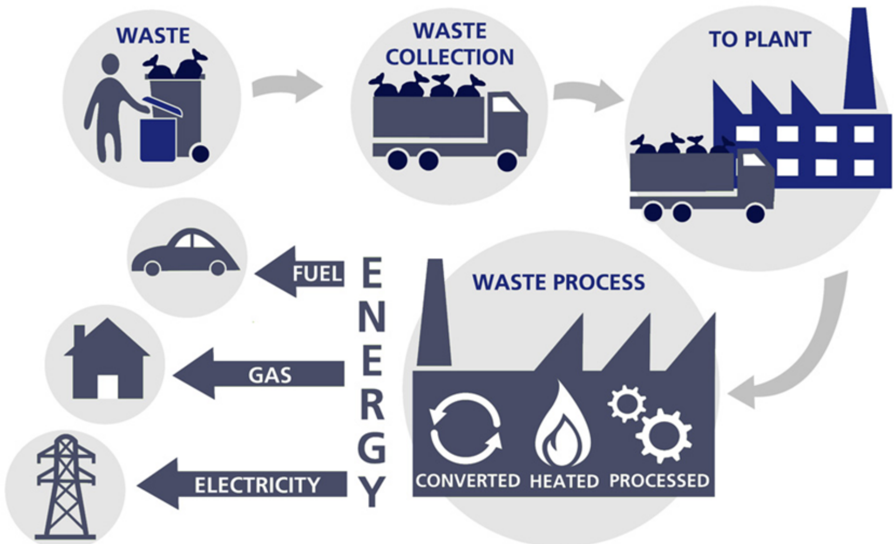

Figure 2. Waste to Energy Process [11]

Society is continually becoming more aware that waste can be a valuable energy and its treatment has the potential to become a sustainable process if suitable technologies can be adopted [12].

2.0 Microbial Fuel Cell (MFC) Technology

MFCs use exoelectrogenic microorganisms to convert the chemical energy stored in biodegradable substances to direct electricity [13]. The bacteria is used as the catalyst to oxidize organic and inorganic matter and generate current [14]. Electrons produced by the bacteria from these substrates are transferred to the anode (negative terminal) and flow to the cathode (positive terminal) linked by a conductive material containing a resistor, or operated under a load (See Figure 3). By convention, a positive current flows from the positive to the negative terminal, a direction opposite to that of electron flow. The device must be capable of having the substrate oxidized at the anode replenished, either continuously or intermittently; otherwise, the system is considered to be a bio-battery [14]. A bio-battery is an energy storing device that is powered by organic compounds and generates electricity from renewable fuels such as glucose, sucrose, and fructose to provide a sustained, on-demand portable power source [15]. Electrons can be transferred to the anode by electron mediators or shuttles, by direct membrane associated electron transfer, or by so-called nanowires produced by the bacteria, or perhaps by other as yet undiscovered means [12].

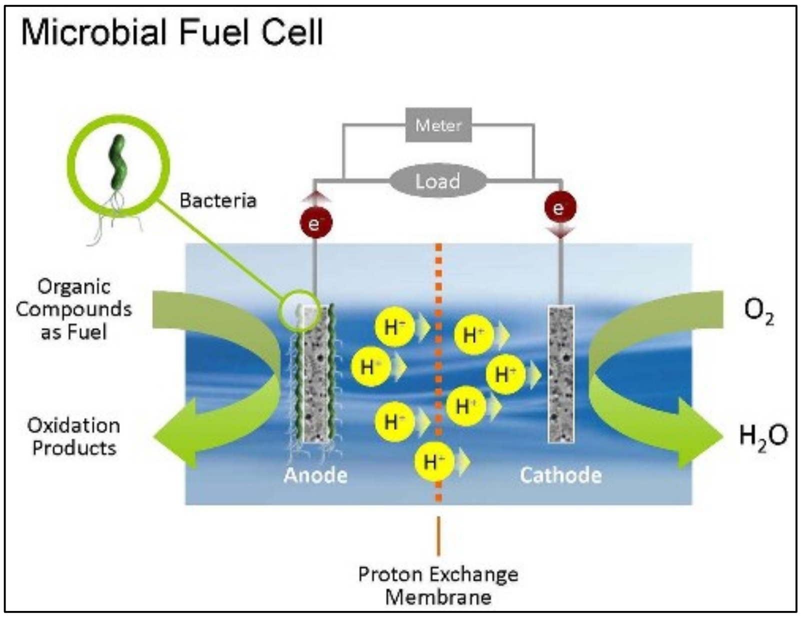

Figure 3. Schematic for Basic Microbial Fuel Cell Components [16]

Virtually, any biodegradable organic matter can be used in an MFC which includes organic waste, food waste, and wastewater. With advances, capturing this power could achieve water infrastructure energy sustainability[14].

3.0 Wastewater

Wastewater treatment plants represent a portion of the broader nexus between energy and water [12]. Collecting, treating, and discharging municipal wastewater to acceptable permit standards requires energy, mostly as electricity, but also as natural gas or other fuels. Within local city and community government, water and wastewater treatment operations are often the largest consumer of energy [17]. Wastewater treatment consumes billions of Watts each year in the industrialized world or 3% of all electrical power produced in the United States each year [18].

3.1 The Primary Treatment Process

The wastewater treatment process includes physical, biological, and chemical processes. Figure 4 shows the general process for wastewater treatment.

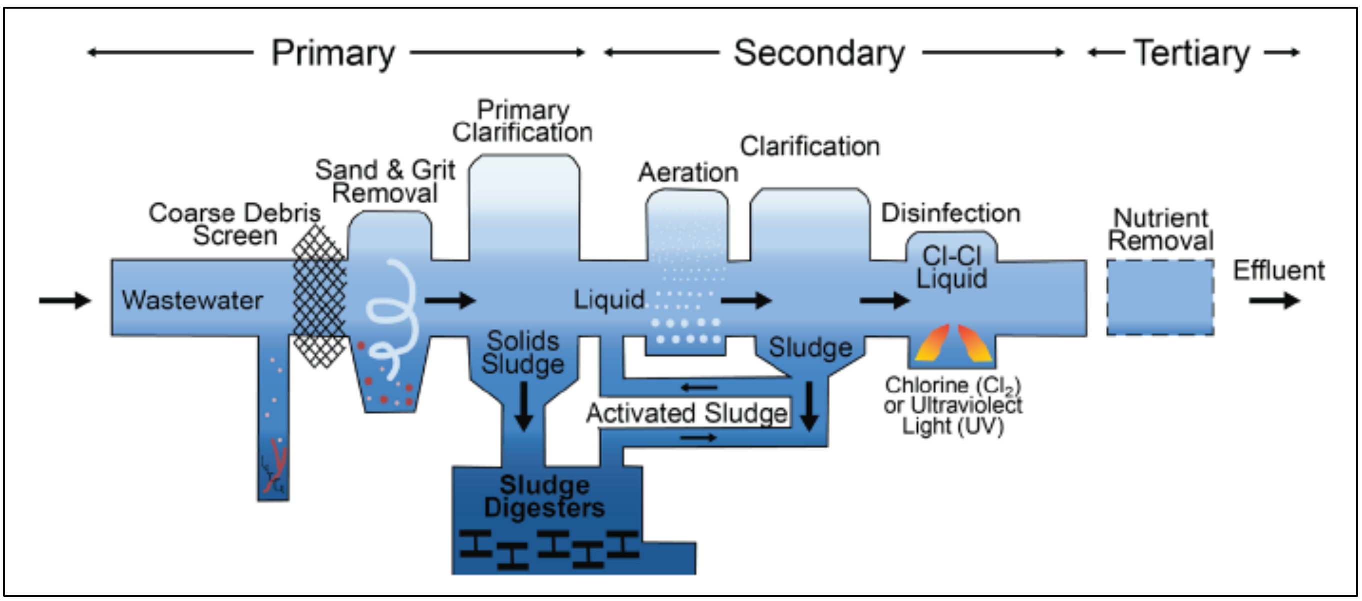

Figure 4. Schematic of the Wastewater Treatment Process [19]

The United States Geological Survey (USGS) provides a concise description of a treatment process: screening, pumping, aeration, removing sludge, removing scum, killing bacteria, and dealing with wastewater residuals [20]. For a description of each process, see reference listing [20].

3.2 Treatment Considerations

Considerations for wastewater treatment include temperature, climate, weather, and organics—all important to microorganisms' survival in water. Another consideration includes whether or not municipal and industrial water will be mixed; industrial water may have pesticides and other chemicals that are harmful to the microorganisms used in the biological process. Precipitation amounts, groundwater intake, and the size of the reservation (for example, how many millions of gallons of water per day flow in) and if there is electricity to run a pump.

Bioelectrochemical systems (BES) including MFCs and microbial electrolysis cell microbial electrolysis cells (MECs) have been investigated as an alternative wastewater treatment process for biomass reduction and simultaneous energy recovery [21]. While both MFCs and MECs have yet to be applied to large scale wastewater treatment, there have been studies conducted, including a trial on MFC implementation for a wastewater treatment plant in Milan that was published in 2015.

4.0 MFC Implementation

While MFCs are still in the research and development phase, there are experiments being conducted around the world. One such example is a trial conducted by E. Martinucci et al. A study from Pennsylvania State University is another example of MFC implementation research.

4.1 Milan-Nosedo Wastewater Treatment Plant

A trial conducted by E. Martinucci et al. tested electric energy production from MFCs directly immersed in a denitrification tank of the Milan-Nosedo wastewater treatment plant (WWTP). The project was the first experimentation of MFCs in the WWTP and it began after preliminary trials performed with lab-scale single-chamber membrane-less MFCs fed with the raw wastewater of the same plant, with the addition of sodium acetate [18]. Six months of operation "indicated that all the tested MFCs were able to supply power, with a density rather inversely proportional to the electrode surface (maxima of 15.5,13, 7.35mW/m2, respectively)" [18]. In the study, current density ranged from about 750mA/m2 maximum in MFCs with the smaller electrode surface to about 500mA/m2 maximum in the medium size MFCs [18]. In the largest MFCs, the maximum current density decreased to less than 150mA/m2 [18]. MFCS output was effected by weather events and water flow variations[18]. Martinucci et al. also found that "vegetation growing on the air facing cathodes did not negatively influence the performances of MFCs up to when they were able to float well balanced on the water" [18].

4.2 Pennsylvania State University Prototype

Research at Pennsylvania State University also highlights MFC implementation efforts. A research team at Pennsylvania State University created a prototype that combined an MFC with a reverse electrodialysis system [22]. Prior to combining the systems, there were problems in scaling up the MFCs in order to generate electricity sustainably [22]. The proof-of-concept device created was capable of generating 0.9 kWh of electricity per kg of organic waste [22]. In order to still be sustainable, plants that consume 1.2 kWh per kg of waste or less, on average, are still able to produce a positive amount of current generation while continuing to perform their conventional function [22]. Additional results of the completed case study included demonstrating that organic matter was treated faster and that MFCs are able to act as a final cleaning stage in the wastewater treatment process [22].

4.3 Parameter Considerations

When implementing MFCs, parameter considerations for calculating theoretical energy estimates and electricity costs and savings include, but are not limited to, the following: chemical oxygen demand (COD), biological oxygen demand (BOD), sludge yield factor, aeration requirements, pumping requirements and influent and effluent characterization. A gram of COD has nearly 5 kJ of energy which can provide a theoretical estimate on the energy available in the wastewater [23].

The yield factor gives the total amount of sludge produced. MFC is advantageous as it minimizes sludge production. Determining electrical consumption in the aeration process for treatment pumping provides an energy comparison as MFCs do not require aeration. In addition to determining the theoretical estimate of energy available in wastewater, other data, including volatile suspended solids (VSS), phosphorous, nitrogen, et cetera can be collected. Any standard wastewater treatment textbook will provide a comprehensive list of parameters that characterize the wastewater and the wastewater effluent.

5.0 Benefits, Challenges, and Opportunities

MFC development is an emerging technology full of potential benefits, practical challenges, and opportunities. The potential benefits of MFCs, as shown in Figure 5, are categorized into four groups: energy benefit, environmental impact, operating stability, and economics.

5.1 Benefits

For energy benefit, MFCs enable direct electric energy recovery, require no need for the aeration process, yield low production of sludge, and adapt to decentralized treatment. The benefits of environmental impacts include reuse, meeting water reclamation standards, low carbon footprint, reduced carbon emissions, and reduced sludge disposal. Operating stability benefits include self-regeneration of microorganisms needed to treat wastewater, resistance to environmental stresses that include toxic substances and environmental fluctuations, and an amenability to real time monitoring and control by means of electrochemical reactions [12]. The economic benefits of MFCs include low operation costs, energy cost savings, and valuable product recovery.

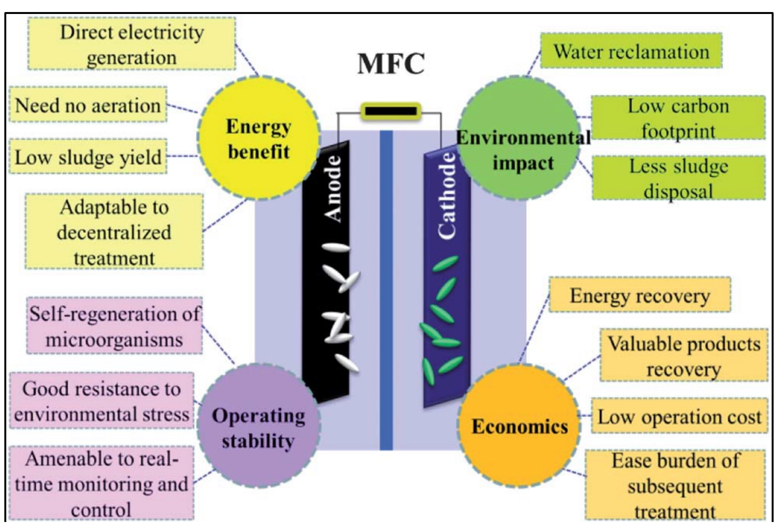

Figure 5. Potential Benefits of MFCs for Energy, Environmental, Operational and Economic Sustainability [12].

5.2 Challenges

Challenges associated with MFC technology for wastewater treatment include the initial capital investment, operation and maintenance expenses associated with energy, chemicals and materials consumption, and deteriorated performance during long-term operation [12]. There are also challenges in scaling up an MFC system for real-world application. Although multiple high-efficiency energy harvesting devices have been developed for single MFCs with low voltage input, they have not been well investigated for an MFC system consisting of multiple modules at a large scale treating actual wastewater. It is not clear whether one energy harvesting system (EHS) per MFC module would work in a multiple-module MFC system and the associated energy loss and maintenance or operation issues [24].

5.3 Opportunities: MFC Deployment on Tribal Lands

Microbial fuel cells (MFCs) represent a completely new method of renewable energy recovery: the direct conversion of organic matter to electricity using bacteria [25]. It has been known for years that bacteria could be used to generate electricity. However, there have been no known studies conducted on tribal lands that would be able to add to the estimated percentage of all renewable energy resources identified. There is a potential for further MFC studies and deployment on tribal lands to expand the tribal renewable energy portfolio. When considering the increased water treatment facilities' operation and maintenance costs, environmental protection considerations, and the growing desire to conserve water, MFC technology may parallel tribal cultural values and beliefs about protecting the environment (sustainable and green practices). There is the potential to further MFC technology to the benefit of indigenous people in the United States.

6.0 Conclusion

MFC development is an emerging technology full of potential benefits, opportunities, and practical challenges. While MFCs have challenges to address before commercial use, current and past studies have shown the continual progression of the waste-to-energy technology. Because of the limited scope of this paper, future studies might include gathering data and information needed to determine wastewater treatment infrastructure on national basis for federally recognized tribes. Such information would help to determine MFC potential on tribal lands. By determining quantity of municipal wastewater and quantifying the amount of Gibbs free energy (mathematical equation determination) available in the waste compound, tribes could estimate the potential electric power generated by wastewater. Not only does MFC technology provide a compelling, innovative solution, it could also address better management of wastewater, using it as a form of energy generation. Using wastewater for clean energy generation could provide a viable addition to community infrastructure systems improvements.

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