MALAYSIAN JOURNAL OF BIOCHEMISTRY & MOLECULAR BIOLOGY

The Official Publication of The Malaysian Society For Biochemistry & Molecular Biology (MSBMB)

http://mjbmb.org

MICROBIAL FUEL CELL AS EMERGING TECHNOLOGY: IMPLEMENTATION POTENTIAL AT CHINI LAKE

Muhammad Najib Ikmal Mohd Sabri[1], Hartini Alias[2], Nor Asniza Ishak[3], Salwa Mohd Zaini Makhtar[4], Husnul Azan Tajarudin[1] and Muaz Mohd Zaini Makhtar[1,5]*

[1]*School of Industrial Technology, Bioprocess Technology Division, Universiti Sains Malaysia, 11800 Penang, Malaysia*
[2]*Center for Innovation and Consultation, Universiti Sains Malaysia, 11800 Penang, Malaysia*
[3]*School of Educational Studies, Universiti Sains Malaysia, 11800 Penang, Malaysia*
[4]*Faculty of Civil Engineering Technology, University Malaysia Perlis, 01000 Perlis, Malaysia*
[5]*Fellow of Center for Global Sustainability Studies, Universiti Sains Malaysia, 11800 Penang, Malaysia*

*Corresponding Author: muazzaini@usm.my

REVIEW ARTICLE

International E-Conference of Science and Biosphere Reserve 2021

Keywords:

Membrane-less microbial fuel cell; bioremediation; bioconversion; electricity; renewable energy

Abstract

The concerns about pollution, resource depletion, and climate change as a result of continued use of traditional fossil and nuclear fuels have sparked an upsurge in interest in renewable energy sources. The energy policies were created to promote the use of sustainable energy. Renewable energy is expected to meet roughly 15-20 percent of the world's energy needs by 2030. As a result, there is a pressing need for innovative technologies that might make renewable resources more accessible to meet this rising demand. This review found tremendous evidence that resources from Tasik Chini may be transitionally converted into electricity generation through the implementation of microbial fuel cell (MFC) technology. MFC are bio-electrochemical devices that work by harnessing the power of respiring microbes and converting organic substrates directly into electrical energy. The device is consisted of MFC reactor, external circuit, and voltage measurement system. Diversified electrogenic bacteria broke down the carbons present in the organic fuel and produced proton, electron, carbon dioxide and electricity. This paper presents the principle and current development in the domain of MFC. It gives potential future applications, including the bioremediation process for sustainable development in Tasik Chini, which simultaneously generates electricity for Orang Asal's daily usage.

INTRODUCTION

Malaysia has a solid variety of energy resources, including non-renewable energy sources like coal, natural gas, and oil, as well as renewable energy sources like hydro, solar, and biomass. Derived on how the generation of electricity significantly affects energy security, climate change and even fluctuation of crude oil price [1]. Nowadays, the world is more circumspect as it moves on to green technology applications, thus addressing the issues of energy and environment simultaneously [1]. According to [2] by 2020, final energy demand by Malaysia is projected will reach 116 Mtoe based on an annual growth rate of 8.1% [2]. Furthermore, the government recognises that global warming and climate change would have a direct impact on Malaysia's economic viability as a developing country [3]. Malaysia also gets involve with transition on implementation of renewable energy since 2000 whereas there are several policies and actions such as eighth Malaysia Plan (MP), Small Renewable Energy Program, National Green Policy and National RE Plan 2010. These all contribute to reducing dependency on fossil fuels and environmental integrity and energy security [4].

CURRENT NON-RENEWABLE ENERGY RESOURCES

Non – renewable energies can be divided into coal, natural gas and crude oil (petroleum). Malaysia has discovered three coal-producing provinces in Sarawak, Sabah, and Peninsular Malaysia. In 1992, coal contributed 9.5 percent of Malaysia's electricity.[5].Comprehensively 57% from 26 265 MW of total estimated plant generating capacity were came from natural gas until end of 2010 [3].

Petroleum production is seen to be declining (Figure 1) after reaching a high of 861.8 thousand barrels per day in 2004. As a result, petroleum production has begun a period of decline [1].Various studies report that the spillage and leakage of crude oil may lead to pollution especially soil pollution as high as 10% w/w [6] due to complex mixtures of several thousands of hydrocarbons [7]. Malaysia has recently experienced a significant increase in air pollution, which has had a negative impact on the ecosystem. Coal, natural gas, and petroleum combustion were responsible for the pollutants. Malaysia's overall CO_2emission has been significantly growing for the past 26 years, as illustrated in Figure 2.

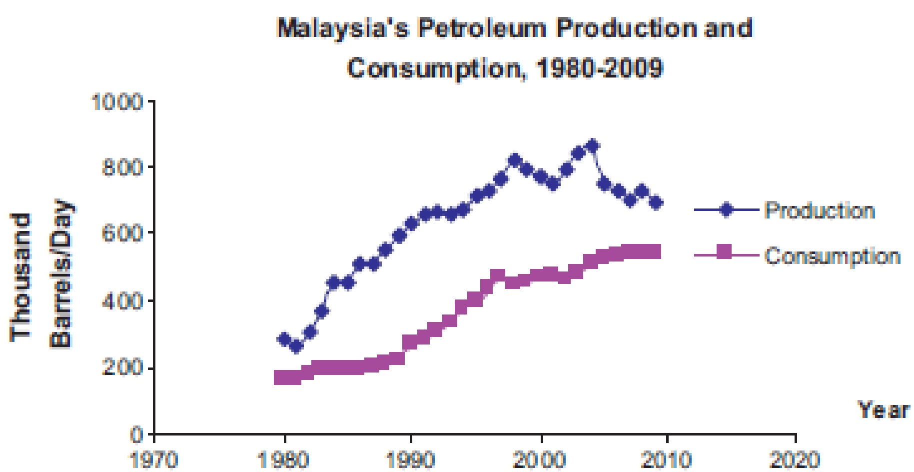

Figure 1: Malaysia’s petroleum production and consumption, 1980 – 2020 [1].

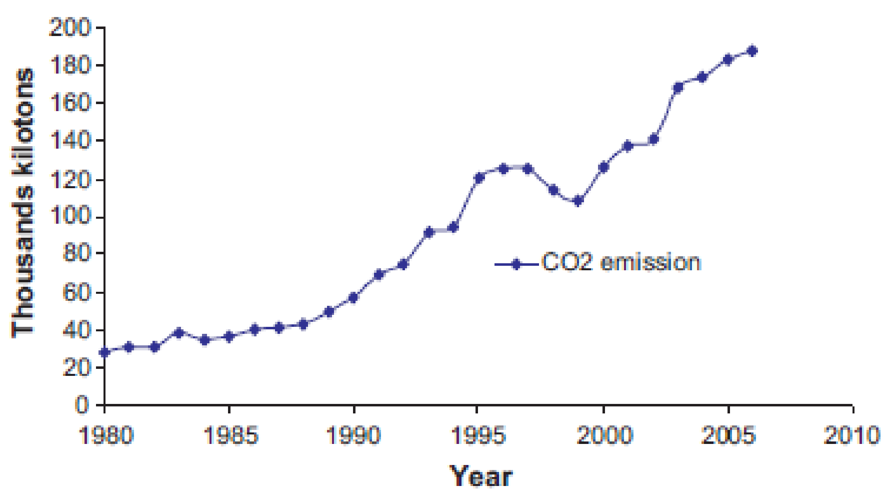

Figure 2: CO_2 emission at Malaysia, 1980 – 2006 [1].

CURRENT RENEWABLE ENERGY RESOURCES

Much of the prior literature on energy has focused on how renewable energy can be generated in a sustainable way, which is defined as living, consuming, and creating in a way that serves current requirements without jeopardising future generations' capabilities [8]. Overall renewable energy clearly can achieves 2℃ climate goal as increment in the share of renewable energy in the final energy consumption from 19% in 2017 to 65% by 2050 [9].

There are hydro, solar and biomass which are mainly contributed in Malaysia. Contribution of hydroelectric about 2.8% (2000 MW) of Malaysia's total electricity requirements and providing 6% of world energy supply [1,10]. The abundance of solar radiation in Malaysia makes it highly potential for solar power generation [11]. Azhari et al. [12] calls our attention on how much high solar radiation generated by Malaysia in August and November which estimated at 6.8 kWh/m^2. Report by Husain et al. [13] highlighted total biomass energy potential is equivalent to 2 – 3% of total power production in the country hence abundant on renewable sources of energy in Malaysia are came from both solar and biomass [1]. Despite of relay on these two sources of energy, let us now turn to newly emerging energy – based technology named as microbial fuel cell (MFC). MFC technology can assist and can convert chemical energy of feedstock into electricity through the metabolic activity of microorganisms which consist of two compartments; anode and cathode separated by an ion – permeable material.

MICROBIAL FUEL CELL HISTORY

Back in 1911 which idea for implementation of microbial fuel cells to produce electricity was first conceived by [14]. The idea showed that it is possible to generate electricity from cultures of the bacterium *Escherichia coli*. Later 1931, research by [15] added some significant knowledge when he reported that the creation of an assembly of microbial half fuel cells stack connected in series capable of producing over 35 V but the current generated through this stack was only 2 mA. A significant influence factor was present on early 1980s in the area of MFC research was received by work of [16], power density improve by usage of chemical mediators as electron shuttle which meant fuel cell would only work if the mediators were in the room.

MFCs have recently been found to include oxidised state. These mediators can easily shorten by trapping electrons from within the membrane and releasing them to the anode, where they are oxidised in the bulk solution in the anodic chamber [17]. Table 1 summarizes preliminary history of MFC started on 1791 until early 2000.

Table 1: Preliminary history of MFC.

Year	Description	References
1791	• Luigi Galvani • Applied current to dead frog legs, the legs twitching • Biological reactions and electric current are closely related.	(48)
1911	• Publication by Potter about MFC report on the ability of microorganisms to transform organic substrate (chemical energy) into electricity. • The production of electrical energy from living cultures either *Escherichia coli* or *Saccharomyces*. • The first MFC proving that biological process produces bioelectricity.	(14,49,50)
1980	• H. Peter Benneto • Succeed in extracting electric power from MFCs • Employed pure cultures to catalyse the oxidation of organics and utilizing artificial electron mediators; to facilitate electron transfer.	(16,51)
Early 2000s	• Two robots were developed; Chew – Chew and EcoBot I • These two robots powered by MFCs	(52,53)

ELECTROGENIC BACTERIA IN MFC

Electroactive or electrogenic microorganisms are the core of the MFC technology. There are also a number of mechanisms for electron transfer such as mediated electron transfer and interspecies electron transfer besides direct electron transfer itself [18].

Generation of electricity through microorganism by exchanging electrons with electrodes while oxidizing organic also called as bacterial exocellular electron transfer principle plays an vital role in anaerobic microbial communities that degrade both inorganic electron acceptors; iron- and manganese- oxide and organic matter for growth [19, 20]. Several decades later, research Anaerobic current productions will occured when there is enrichment of Clostridia on the anode biofilm due to nitrogen cycle; N_2- fixing bacteria [21].There were three methods to transfer the electron to the anode; [1] direct transfer from the cell walls of microbes to the anode surface, [2] using biomolecules secondary to shuttle electrons to the anode or [3] the transfer of electrons through a conductive appendages, called "nanowires", planted by microbes (Figure 3).

Table 2 and 3 illustrated the famous and frequent used of bacteria in MFC. Research conducted by [22] highlighted that bacterial diversity and operating environment affect the biodegraded products generation. This phenomena can be seen on the reductive breakdown of azo bonds been further degrade through aerobic condition by the presence of several oxidoreductases also called as oxidative degradation [23].

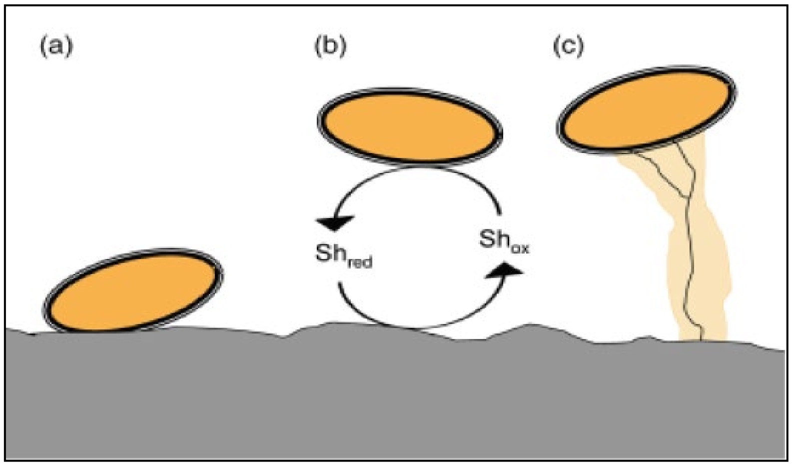

Figure 3: Electron transport in microbial fuel cells (a) direct electron transfer, (b) an electron shuttling and (c) solid conductive appendages, called "nanowires" [24].

Table 2: Overview of axenic bacteria culture applied in MFCs.

Organism	References
Shewanella putrefaciens	(54,55)
Geobacter sulfurreducens	(8,56)
Geobacter metallireducens	(57,58)
Desulfuromonas acetoxidans	(58)
Rhodoferax ferrireducens	(26)

Table 3 Overview of mixed bacterial culture applied in MFC.

Microorganisms	Substrate	Anode	Current (mA)	Power (mW/m^2)	References
Mixed seawater culture	Acetate	Graphite	0.23	10	(58)
	Sulphide/acetate		60	32	(59)
Mixed active sludge culture	Acetate	Graphite	5	-	(60)
	Glucose		30	3600	(61)
	Sewage	Woven graphite	0.2	8	(62,63)

MFC CONCEPT

Fundamentally MFC construct through duo of terminals which are negative (anode) and positive (cathode); microorganism inside MFC plays a vital role for generate electrons. The anode terminal oxidised organic matter like fuel, yielding CO_2, electrons, and protons, whereas the cathode terminal received electrons generated by an external circuit owing to electrophilic attraction. There will be three concepts in total: biological, chemical, and electrical (Figure 4).

that are most important for biological metabolism inside cell. Major sources of energy in cellular processes is the phosphate group, it complicated name is adenosine triphosphate (ATP). In MFCs energy production occurs when electrons were passed through an electron transport chain (ETC) and protons are translocated across the cell membrane to generate energy in the form of adenosine triphosphate (ATP).

Secondly chemical reaction that usually occur in MFC system are reduction and oxidation popularly called as redox reaction [24, 25]. MFC developed as anode catalyst where microorganism is used as biocatalyst for the redox reaction. Capability ofelectrogenic bacteria for generating and transferring electrons through nanowires (*Geobacter sulfurreducens*) and electron shuttle (*Pseudomonas aeruginosa*) [25, 26].

Next, electrical energy yield occurs when biomass-based materials oxidise, resulting in the formation of free electrons that pass through an external circuit in MFCs [27]. Production electrical power (W) based on the rate of electrons moving through the circuit; current (amps) besides electrochemical potential difference (V) across the electrodes [28].

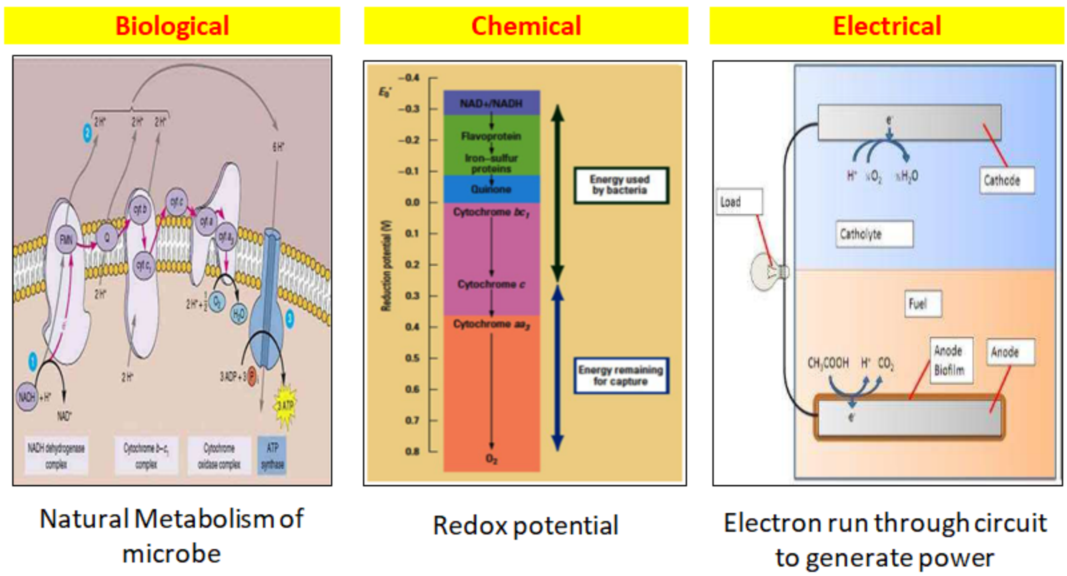

Figure 4: Three concepts in MFC [47].

MFC CONFIGUREUREURATION

Along the appropriate optimization of architecture (Figure 5), microbial fuel cells are able to power a wide range of devices such as power sensors for environmental parameters monitoring at various intervals, store energy in external storage device; capacitor and power devices placed under water environment [29, 30]. Single chamber, double chamber, tubular membrane, stack design, and flat – plat MFCs are all popular designs.

Single chamber MFC designed to characterize the performance either anodic or cathodic chambers separately. Common single chamber possessed aeration on anodic chamber without included cathodic chamber. MFCs' internal resistance is reduced, resulting in increased electricity output [31].Then there's the dual chamber. One cathode chamber and one anode chamber were joined by a bridge and divided by a proton or cation exchange membrane, which allowed protons to pass through to the cathode while blocking oxygen passage into the anode. Chemically the plain carbon cathode was catalyst and coated in ferricyanide due to platinum expensively [31, 32].

Tubular membrane orientation practically placed as closely as possible inside reactor developed 112 – 240 mV higher than outside the reactor. Based on Zuo et al. [33] higher power densities of tube cathode were curbed by internal resistance of reactor, which was measured to range from 66 to 131 Ω. While stack MFC can be separated into parallel and series circuits, copper wire is used to connect electrodes and screw fasteners are used to hold them together. Both research by [34, 35] observed that effect of maximum power output per MFC unit no visible adverse which coulombic efficiency diverged greatly in two arrangements with parallel connection giving about six times efficiency more when both the series were operated at the same volumetric flow rate. Finally, when compared to single chambered MFC, flat – plat can provide a maximum power density for domestic wastewater of 72 mW/m2, an increase of 2.8 times. Basically the structure of flat – plat similar to chemical fuel cell whose designed by Min and Logan [36].

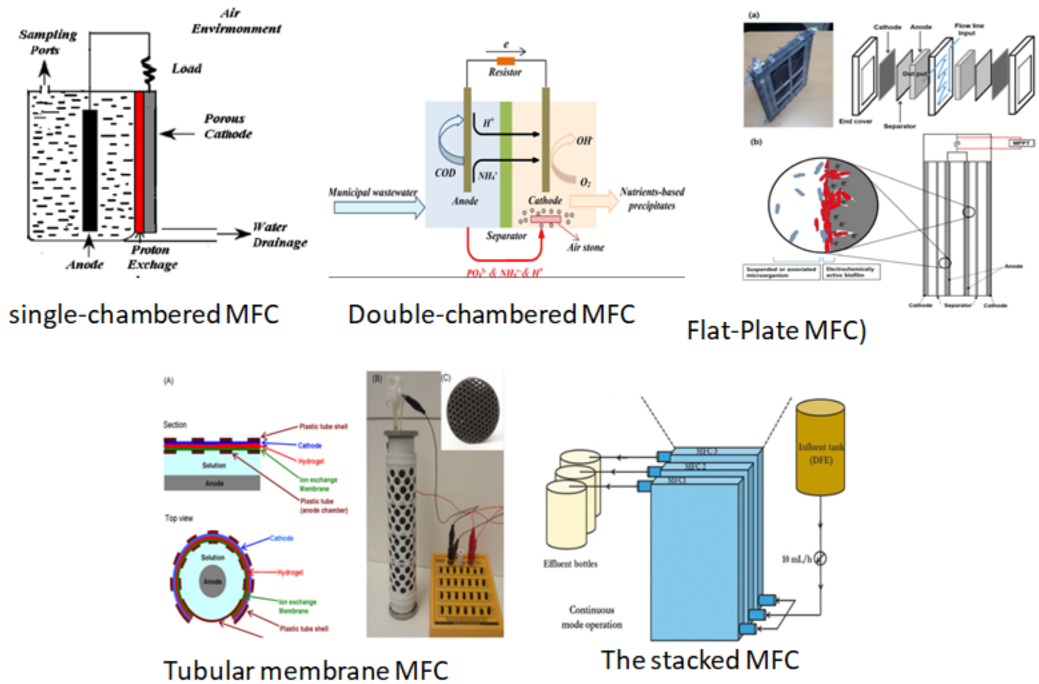

Figure 5: Typical configurations of MFC.

SUBSTRATE FOR ELECTRICITY GENERATION IN MFC

MFC may generate power from a variety of substrates. The substrate consist of complex that may contribute as nutrient for microorganisms to conduct metabolism and delivery energy; inside MFCs, which are the most important ingredients for determining electricity [37]. Research done by [38] demonstrated that effectiveness and economic viability of converting organic wastes (Figure 6) to bioenergy are determined by the waste material's qualities and components, such as the chemical structure of the organic compound that could be transformed into a product or fuel. Pure chemicals such as glucose, ethanol, and cysteine as an amino acid have been used in MFC research to generate electricity, according to current studies. There had been studies on the generation of energy directly from complex organic wastewater, such as municipal wastewater, industrial wastewater and ocean sediments. Industrial wastewater can categorized into starch and brewery wastewater [39].

Lignocellulosic composed of three major components named cellulose, hemicellulose and lignin. The complex structures of lignicellulosic causes trouble for understanding fermentation performance of cellulose, hemicellulose and lignin in biogas production [40]. Furthermore, because of their low cost and environmental concern, lignocellulosic biomass is gaining a lot of attention as a precursor for the creation of carbon-rich materials. Figure 6 summarized sources that include lignocellulosic as well.

POTENTIAL CARBON SOURCES AT TASIK CHINI

Tasik Chini is a lakeside located at Pekan District, the south – eastern of Pahang. Tasik Chini is the second largest freshwater lake in Malaysia after Tasik Bera, which covers an area of 202 ha [41]. Tasik Chini was previously recognised as a nature region with a diverse range of flora and fauna, as well as biological resources such as 51 types of low forest plants. There are further mountains known as Mount Chini, which are densely forested. Because of its unique habitat and strong tourism potential, it is a popular tourist destination. Tasik Chini has been endorsed as the pioneer of Reserve Biosphere in Malaysia [42].

As reported by [43], Pahang's government has set aside 8.1 hectares of critical land for a natural laboratory under the supervision of Universiti Kebangsaan Malaysia's Tasik Chini Research Centre (UKM). This research centre was created in accordance with Pahang's Rancangan Struktur Negeri 2050 for conservation and long-term development along the Tasik Chini [44]. Scientist from UKM research centre planned constructively to replanting trees in watershed areas estimated as much as 11k trees in the deforested areas. There will be an abundance and renewability of cellulosic and lignocellulosic materials sourced from Tasik Chini coming of this conservation. Dead leaves, forestry leftovers, and lakefront mud, for example, are comprised as carbon resources yet converted into renewable energy through MFC technology. These all can be summarized in Table 4.0 as list up the most common used for lignocellulosic biomass applied in MFC.

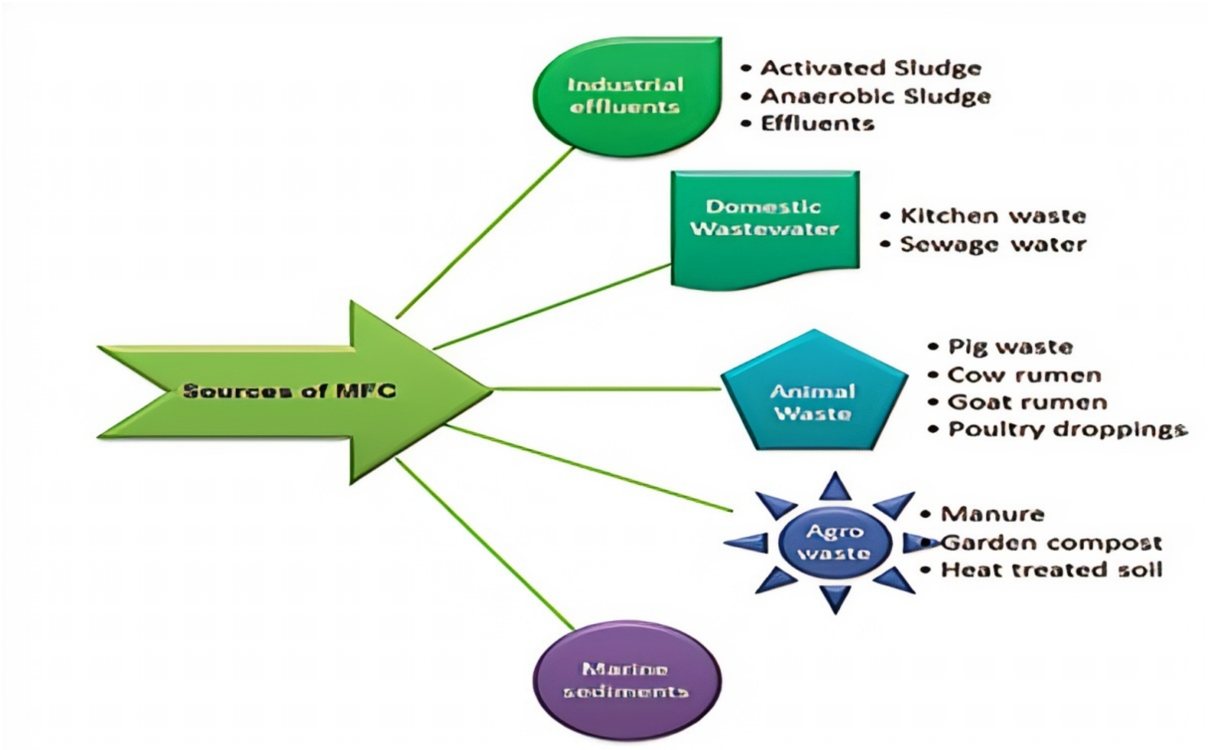

Figure 6: Type of source of MFC.

IMPACTS OF MFC TOWARDS TASIK CHINI

Energy is vital to humanity's survival. Limited access to modern electricity is a common problem in remote areas. Biomass energy is also a renewable energy source that can be used as an alternative power source, perhaps reducing the strain on those indigenous people, also known as Orang Asli, on their daily expenses. Table 4 summarized five villages that located along Tasik Chini. Based on [41] about 55% of monthly household income been used to buy gasoline. While Figure 7 exhibits the impact of MFC for bioremediation and electricity generation toward Tasik Chini.

According to a previous study on Orang Asli entrepreneur development, the majority of Orang Asli delved into the handicraft sector and earned up to RM 2000 a month [45]. Perhaps, these handicraft wastes can be well utilized and converted into bioenergy integrated technology of MFC. It has established that MFC technology can utilized all those wastes into fuels [38] thus can provide a sources of electrical energy for those aboriginal; Orang Asli.

Based on Figure **7**, MFC technology had given a numerous advantage which can reduce global warming, alternatives of natural sources, low dependency on fossil fuel, gain a self – sustain, generation own electricity to power plant and usage as purification of natural water. Malaysia is one step moving toward application of Sustainable Development Goal (SDG), by implementation of MFC technology SDG 13 (Climate Action), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 6 (Clean Water and Sanitation) can be achieved [46].

Table 4: List of substrates lignocellulosic based with MFC applications.

No	Type of biomass (substrate)	Type of MFC	COD removal (mg/L)	Voltage	Power density	Reference
1	Grass	• Mediator – less single chamber • Anode and cathode placed in parallel with distance of 1.4 cm.	1500	217 Ω	67 ± 1 W/m3	(64)
2	Leaf	• Double chambered • Temperature 33±2C	3000	External=10 Ω Internal=198 Ω	5.6 W/m3	(65)
3	Rice straw	• Single-chamber air-cathode • Air-cathode MFCs, biofilm was formed on the water-facing side the cathode	400	524.7 ± 3.2 mV	137.6 ± 15.5 mW/m^2	(66)
4	Bamboo	• Arcrylic MFC • Anode and cathode chamber	75 – 80%	0.76	0.3 – 0.6	(67)

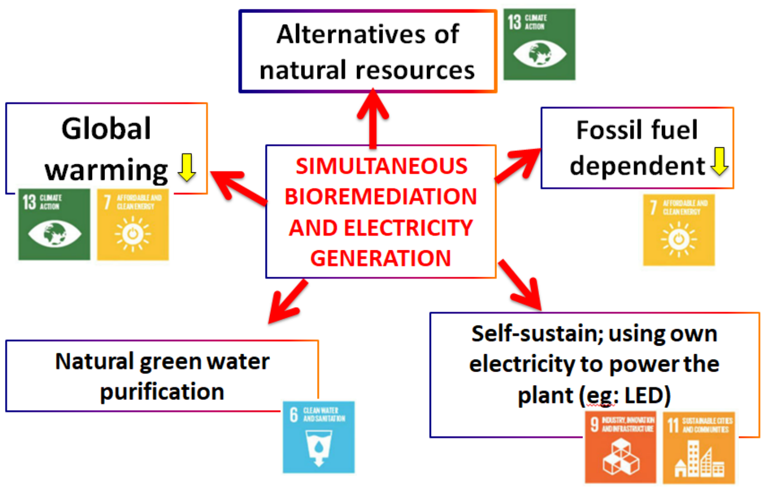

Figure 7: Correlation on Bioremediation and Electricity Generation through MFC application.

CONCLUSION

The numerous substrates that have been employed in MFCs for current production as well as waste treatment are summarised in this paper. MFC is a potential method for producing electricity from organic materials; particularly organic waste of various origins.MFC has various advantages because it deals with the creation of power from waste materials. For example, it produces low-cost electricity from waste materials; people will be able to create power in their houses all year because wastes are freely available, and MFC will lead to waste clean-up thus, it can be used as an alternate method for bioremediation to sustain the water quality of the Tasik Chini too.

ACKNOWLEDGMENT

The authors would like to thank the Universiti Sains Malaysia for the financial support of this study via the Short Term Grant (304/PTEKIND/6315353), and the support from the Ministry of Higher Education Malaysia through Fundamental Research Grant Scheme (FRGS)(203/PTEKIND/6711823). The authors have declared no conflict of interest for the manuscript.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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