Chapter 6
Green Energy Conversion Systems

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Abstract This chapter develops a technological solution for waste management at the source. A device containing a soil microbial fuel cell (MFC) is designed for reliable renewable energy production using kitchen waste. The innovative methodology and constructed green energy conversion system produces 'eco-friendly' electricity by capturing energy produced by naturally occurring microbial metabolism of organic materials such as food scraps, manure and plant waste. Biomass that may be used includes municipal solid waste and agricultural by-products. The electricity generated by soil MFCs can be utilized immediately by USB devices. The developed system removes and sequesters carbon dioxide and methane gas, creating a clean, environmentally responsible supply of multiple power types. The overall process provides an option for current power generation and alleviates the need for

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J. N. Furze et al. (eds.), *Earth Systems Protection and Sustainability*,
https://doi.org/10.1007/978-3-030-98584-4_6

fossil fuels. Green energy conversion systems enable domestic power generation and create the possibility for reduced dependence on imports for energy needs.

Keywords Kitchen organic waste · Soil microbial fuel cell · Bioelectricity

6.1 Introduction

The microbial fuel cell (MFC) is a novel and sustainable approach to harvest electricity through a natural route. This green energy conversion system (GECS) utilizes organic-rich waste; predominantly carbohydrates are used as an electrolyte, and metabolic decay produces electrical energy (Logan and Regan 2006; Ren et al. 2014). The MFC couples with conventional electrochemical cells allowing the bio-catalytic action of microbes to harvest the bioelectricity. Potter (1911) proposed the concept of metabolic electricity, to draw electricity using exoelectrogens' bio-catalytic life (Borole et al. 2009). Recently the microorganism potential has emerged as a multi-dimensional technology due to its numerous advantages over conventional energy resources and existing waste treatment systems (Bond et al. 2002; Bond and Lovley 2003). MFC technology has received increased research interest in recent years because of its potential, particularly for bio-energy production and waste treatment (Hai et al. 2007). Microbial fuel cells are a novel addition to the inventory of alternative energy sources which have minimal or no net carbon dioxide emission (Shukla et al. 2004).

Electricity production using microbial cultures was first reported early last century by Potter (1911). MFCs have been described as bioreactors that convert energy in chemical bonds of organic compounds, into electrical energy through the catalytic activity of microorganisms under anaerobic conditions (Du et al. 2007). MFC technology represents a novel approach of using bacteria for the generation of bioelectricity by oxidation of organic waste and renewable biomass (Lovley 2006). In the MFC, the energy stored in chemical bonds in different organic compounds is indirectly converted into electrical energy through enzymatic reactions conducted by microorganisms (Kumar et al. 2016b). Exoelectrogenic bacteria commonly exist in the soil and can transfer electrons outside their cells through direct contact (Nicholls 1982; Kumar et al. 2016a). Most of the smallest and most interesting organisms on Earth are in the soil (Rabaey et al. 2004). The performance of MFCs depends on several factors, including microbial activity, substrate type, concentration and electrode material (Yong et al. 2014). Several factors can improve MFC performance to produce electricity (Moat et al. 2002; Kim et al. 2007; Yangyue et al. 2014). Determining which specific factors and conditions affect MFCs is crucial.

This chapter investigates an MFC in peat soil bioelectricity production, with organic kitchen waste being used as an electrolyte solution to moisturize the soil. Peat soils are widely found in southern Indian regions, local potential may be optimised for renewable electricity generation.

6.2 Microbial Use for Dual Purposes

Soil, manure or cow dung is beginning to attract research attention as suitable inoculums for MFCs designed for the dual purposes of remediation and electricity generation. This chapter explains and compares the fundamental design features of MFCs for waste management at the source level. Herein the concept has been targeted at generating electricity from peat soil and cow dung, utilizing microorganisms present in the ground and investigating the performance of the soil microbial fuel cell across varied external loads.

6.2.1 *Soil Microbial Fuel Cell (SMFC) Design*

The SMFC dimensions used in this study were 25 cm × 12 cm × 50 cm. The electrodes used in the unit were air cathodes of activated carbon and anodes of galvanized iron, which were round-shaped, installed sequentially, as shown in Fig. 6.1a, b.

The fuel cell contained a capacity of 2.5 kg of peat soil. The electrode's dimensions had a length of 25 cm and a radius of 2.5 cm. The fuel cell unit consisted of one positive electrode and one negative electrode.

The developed SMFC of Fig. 6.1 was used with the addition of 1 kg of organic waste, as shown in Fig. 6.2a, b.

Organic waste was added to the soil to increase humidity and supply nutrients, thereby increasing microbial populations. To investigate the effect of organic debris on the electricity generated, we measured the electrical potential of the SMFC for 30 days. Measurement of voltage and current was carried out every 24 hours. Voltage and current data are seen in Table 6.1.

Voltage and current generated using organic waste are higher than regular peat soil (contact authors for details). Organic waste contains minerals with positively

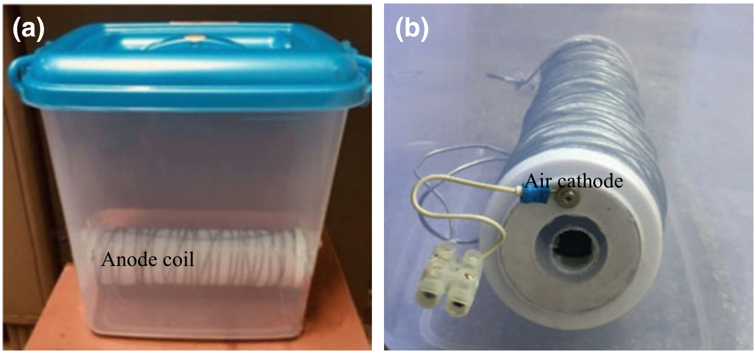

Fig. 6.1 Soil microbial fuel cell with: (**a**) anode coil; (**b**) air cathode

Fig. 6.2 Soil microbial fuel cell with: (**a**) peat; (**b**) kitchen wet waste

and negatively charged ions. Thus, the electrochemical process or change of chemical energy into electrical energy becomes significant because the electrodes become more conductive and less resistant. The SMFC contained 2.5 kg peat soil and 1 kg mixed organic waste which was obtained from kitchen sources in this study. An air vent system was fitted on the top side of the cover of the unit to trap moisture from the organic waste and release water as an electrolyte, increasing the humidity of soil (Wetser et al. 2015). Voltage and current are known to be higher in moist conditions (Reguera et al. 2006). The voltage and current generated from the SMFC in different ambient conditions were investigated. An ongoing objective of this and other studies is to determine the optimum conditions in which the SMFC produces voltage and current values (Mulyadi and Arsianti 2018; Sedighi et al. 2018; Truong et al. 2019; Lee et al. 2020), as shown in Fig. 6.3.

This study chose an SMFC with a boost converter circuit, to raise the generated voltage and current to a practical level.

6.2.2 *Design of Boost Converter*

The boost converter circuit was used to raise the direct current voltage level to a higher level direct current voltage produced by the SMFC. The circuit design is shown in Fig. 6.4a, b.

The SMFC was connected to a 3 W LED lamp load. The set parameters of the boost converter were output voltage 4.7 V, with efficiency (η) of 85%. The minimum voltage was 0.4–0.8 V. The duty cycle is determined using Eq. (6.1). The resultant calculation of our experiment is also shown.

$$D = 1 - \frac{V_{\text{in}}(\min) * \eta}{V_{\text{out}}} \tag{6.1}$$

Table 6.1 Soil microbial fuel cell voltage and current measured outdoors at ambient temperature for 30 days

Day	Open circuit voltage Volts (V)	Short circuit current density Amps (A)	Ambient temperature (°C)	Remarks
1	0	0	21	No voltage and current developed
2	0.16	2	25	Microamps
3	0.20	21	24	Microamps
4	0.30	100	21	Microamps
5	0.35	150	23	Microamps
6	0.40	200	21	Microamps
7	0.45	250	22	Microamps
8	0.49	350	21	Microamps
9	0.50	500	21	Microamps
10	0.56	700	26	Microamps
11	0.58	1	21	Milliamps
12	0.60	2	21	Milliamps
13	0.65	5	20	Milliamps
14	0.69	10	21	Milliamps
15	0.75	13	21	Milliamps
16	0.78	15	23	Milliamps
17	0.80	17	21	Milliamps
18	0.85	20	23	Milliamps
19	0.88	21	23	Milliamps
20	0.90	22	24	Milliamps
21	0.92	23	26	Milliamps
22	0.93	40	28	Milliamps
23	0.95	45	31	Milliamps
24	0.85	32	22	Milliamps
25	0.83	29	23	Milliamps
26	0.82	25	21	Milliamps
27	0.81	31	22	Milliamps
28	0.80	32	22	Milliamps
29	0.75	33	21	Milliamps
30	0.78	35	21	Milliamps

$$D = 1 - \frac{0.5^{*}0.8}{3.2}$$

$$D = 0.86718$$

The ripple current on the inductor load (I_L) can be obtained through Eq. (6.2):

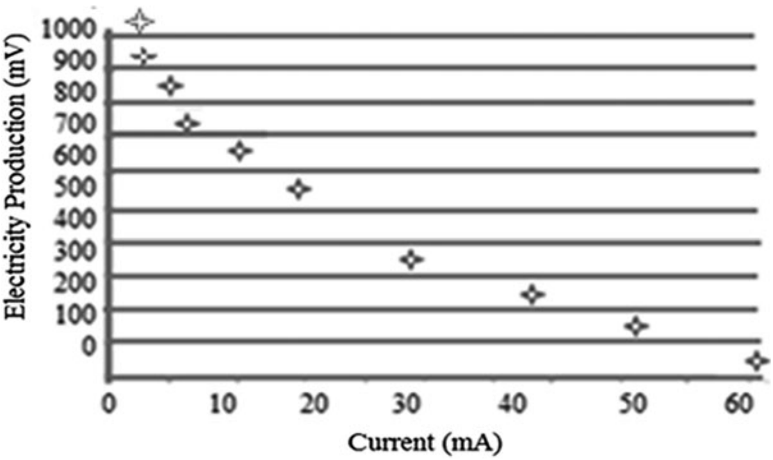

Fig. 6.3 Characteristic curve and electricity production measured as a function of voltage in millivolts (mV) and current in milliamps (mA)

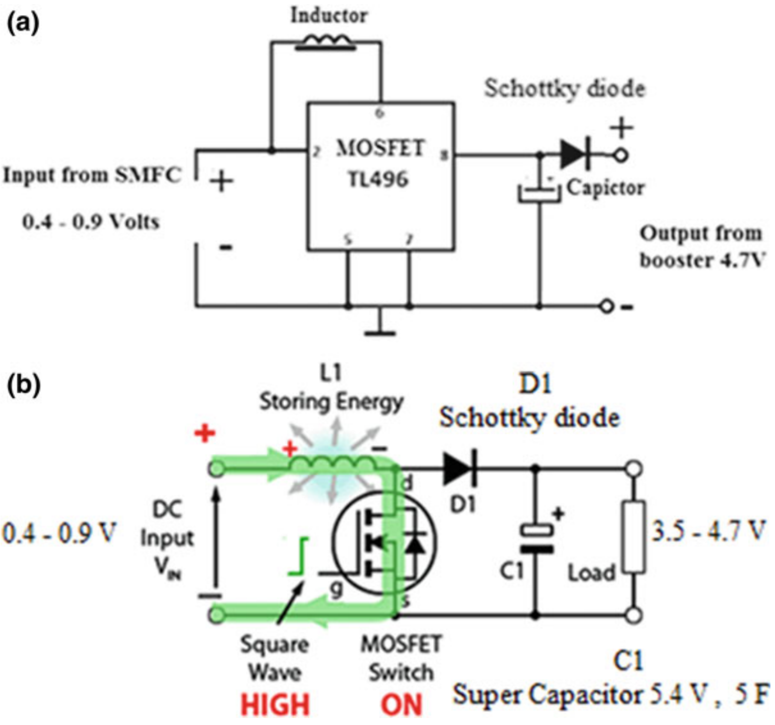

Fig. 6.4 Circuit diagram of the boost converter: (**a**) circuit representation; (**b**) direct current boosting and energy storage

$$\Delta I_L = \frac{V_{\text{in}} * (V_{\text{out}} - V_{\text{in}})}{L * \text{fs} * V_{\text{out}}} \tag{6.2}$$

where L is load of the inductor, fs is switching frequency and V_{in} and V_{out} are voltage in and out, respectively.

The ripple current on the inductor was obtained as shown in Eq. (6.3). A 940 micro-henry (μH) inductor was used in this circuit. A switching frequency of 20 kHz was used.

$$\Delta I_L = \frac{0.5 * (3.2 - 0.5)}{940 * 10^{-6} * 20 * 10^3 * 3.2}$$

$$\Delta I_L = 0.0224 \text{ Amps} \tag{6.3}$$

The capacitor value in the boost converter circuit can be obtained by using Eq. (6.4). The maximum output current (I_{OUT} max) was 0.25 A.

$$C_{\text{out (min)}} = \frac{I_{\text{out (max)}} * D}{\text{fs} * V_{\text{out}}} \tag{6.4}$$

$$C_{\text{out (min)}} = \frac{0.25 * 0.8671}{20 * 10^3 * 3.2}$$

$$C_{\text{out (min)}} = 3.3874 \ \mu\text{F}$$

6.2.3 *Experimental Test of the Soil Microbial Fuel Cell*

The SMFC with a booster circuit was tested for transfer of the electrical loads. The SMFC with booster circuit schemes can be seen in Fig. 6.5.

Figure 6.6a–c shows the SMFC with a 3 W USB LED lamp, 1 W USB LED light and 1 W USB fan, respectively, demonstrating the versatility and potential uses of the system.

6.3 Results and Discussion of Soil Microbial Fuel Systems: Potential for Membership in Renewable Energy Mixes

We investigated the performance of the SMFC with the 3 W LED lamp load for 7 days. Measurement of the generated voltage and current by the SMFC was taken daily at 10-minute intervals for 1800 minutes. The voltage and current data

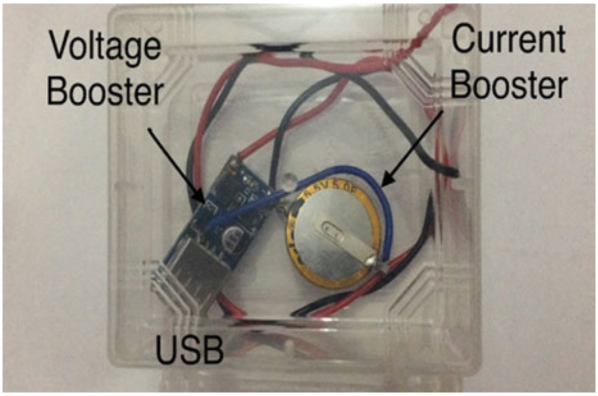

Fig. 6.5 Voltage and current boost converter

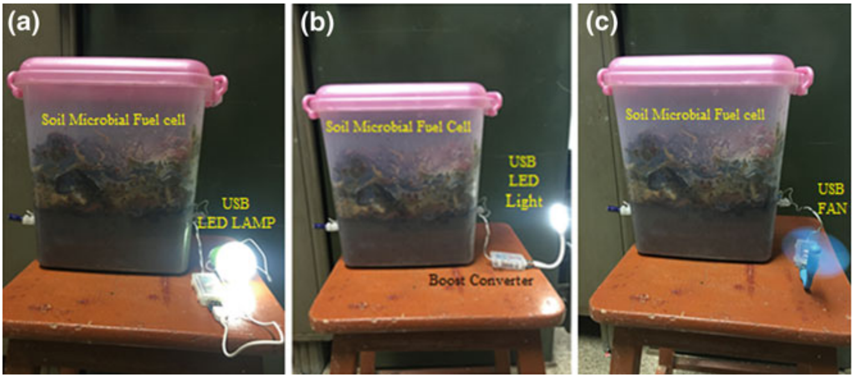

Fig. 6.6 Electrical loads powered by the soil microbial fuel cell: (**a**) a 3 W USB LED lamp; (**b**) a 1 W USB LED light; (**c**) a 1 W USB fan

generated by SMFC can be seen in Figs. 6.7 and 6.8. The output voltage generated by the SMFC in the first minute reached 1.00 V. This was the peak voltage generated by the SMFC with no load. The voltage value reached stability at 0.58 V in 120 minutes duration. The load voltage continued to be stable at 0.29 V until the seventh day at 1800 minutes. The boost converter circuit increased the SMFC load voltage from 0.29 V to 3.7 V.

Example data of the voltage of the SMFC can be seen in Fig. 6.7. Example data of the SMFC current measurement for 7 days can be seen in Fig. 6.8. In the first minutes, the current produced by the SMFC was 45 mA under a short circuit. The current continued to supply to the load for 7 days, the peak current of the SMFC under load was 23 mA.

The electricity power generated by the SMFC is shown in Fig. 6.9. The maximum power of the SMFC with no load was 17 mW. Electricity generated decreased. However, the SMFC's electrical power lasted up to 1800 minutes; the minimum value produced without load was 11.98 mW and 5.11 mW with load.

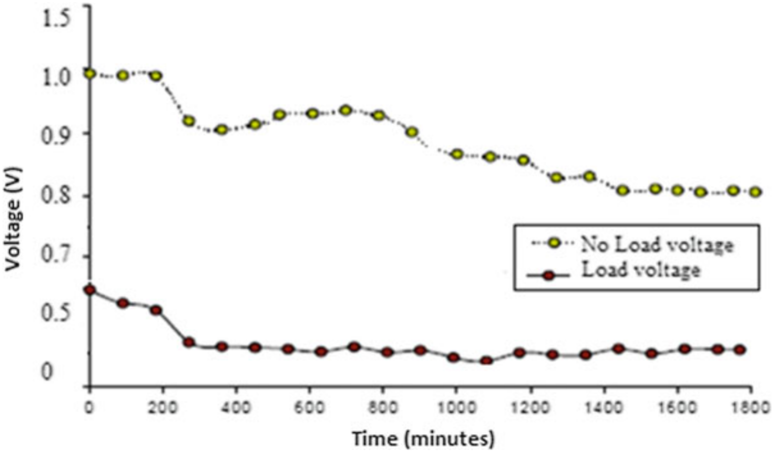

Fig. 6.7 The soil microbial fuel cell power generation

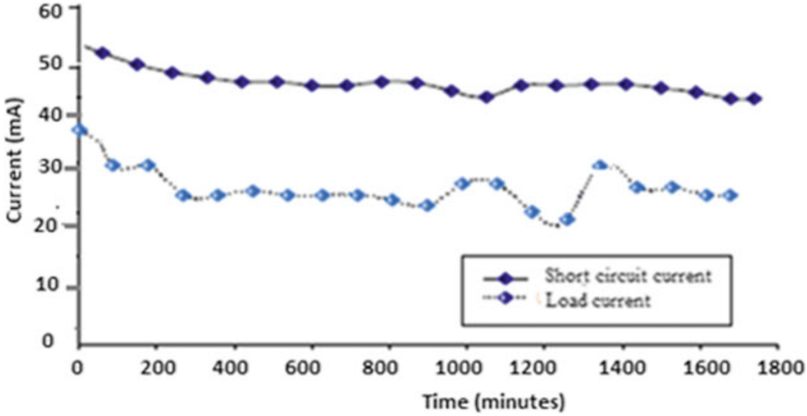

Fig. 6.8 Short circuit current and load current density of the soil microbial fuel cell

Although the substrate retrieval interval requires measurement, organic compound content and capacity to generate power decrease due to continual microbial degradation. Further, incremental internal resistance caused the decline in electricity generated by the SMFC. Using a conventional battery voltage source, the output of the LED lamp light intensity was 270 lumens; when powered by the SMFC it was 26 lumens in the first minute. Using a 3.7 V lithium-ion battery, the LED lamps lit up for 1500 minutes with a minimum light strength of 32 lumens; the SMFC powered the LED lights for up to 900 minutes with a last-minute light intensity of 25 lumens. The light intensity achieved with the SMFC is seen in Fig. 6.6a. The output of light produced is strongly influenced by voltage and current of the source.

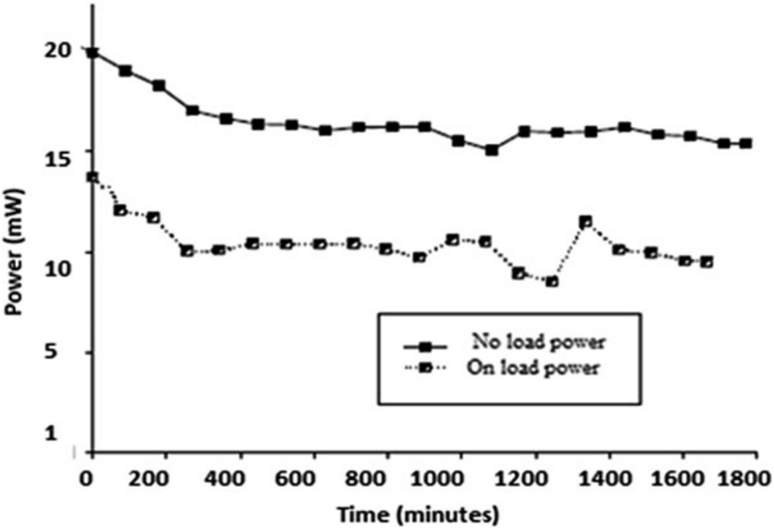

Fig. 6.9 Power delivered by the soil microbial fuel cell with and without load demand

The voltage and current generated by the SMFC were 0.50 V and 36 mA. The current produced by the SMFC was half of the current obtained by the battery source. This caused the light intensity produced by SMFCs to be lower. The SMFC may be proposed as a renewable energy mechanism for hybrid street lights, emergency lamps, USB device chargers, mobile chargers and remote areas that have not obtained an electrical network (Shantaram et al. 2005).

6.4 Conclusion

The present chapter demonstrated a prototype SMFC, an activated carbon block-based microbial fuel cell that used a kitchen based organic waste with soil: biodegradable hydrocarbon contaminant assisted bioelectricity generation. On average, a 250 mW/m^2, 550 mV increase in energy production efficiency resulted from the use of biodegradable contaminants. This study indicates that the SMFC is feasible for the treatment of organic waste contaminants. The SMFC with the current booster circuit can produce stable electricity of 17.2 mW and can power LED lights for 90 minutes with the highest and the lowest light intensity of 260 lumens and 12 lumens, respectively. Future work should investigate the composition of microbial communities with differing substrate addition to effect electrical power generation. The SMFC can be proposed as an alternative renewable energy mechanism under bio-energy. The SMFC is effective with low cost and simple maintenance, and may be used to produce low-power electricity for public street lighting or domestic settings. The importance of bioelectricity generation in treating complex and recalcitrant compounds of organic waste has been illustrated. Biodegradation effected a range of high power output to low power output. The data of voltage and current measured from the analysis of SMFC for 30 days analysis also illustrates the sustainable capacity of SMFCs. SMFCs may be optimised in terms of their microbial populations. Green energy conversion systems hold great potential for future power generation.

References

Bond DR, Holmes DE, Tender LM et al (2002) Electrode-reducing microorganisms that harvest energy from marine sediments. Science 295:483–485. https://doi.org/10.1126/science.1066771

Bond DR, Lovley DR (2003) Electricity production by *Geobacter sulfurreducens* attached to electrodes. Environ Sci Technol 69(3):1548–1555. https://doi.org/10.1128/aem.69.3.1548-1555.2003

Borole AP, Hamilton CY, Vishnivetskaya T et al (2009) Improving power production in acetate-fed microbial fuel cells via enrichment of exoelectrogenic organisms in flow-through systems. Biochem Eng J 48(1):71–80. https://doi.org/10.1016/j.bej.2009.08.008

Du Z, Li H, Gu T (2007) A state of the art review on microbial fuel cells: a promising technology for wastewater treatment and bioenergy. Biotechnol Adv 25:464–482. https://doi.org/10.1016/j.biotechadv.2007.05.004

Hai FI, Yamamoto K, Fukushi K (2007) Hybrid treatment systems for dye wastewater. Crit Rev Environ Sci Technol 37(4):315–377. https://doi.org/10.1080/10643380601174723

Kim BH, Chang IS, Gadd GM (2007) Challenges in microbial fuel cell development and operation. Appl Microbiol Biotechnol 76:485–494. https://doi.org/10.1007/s00253-007-1027-4

Kumar R, Singh L, Wahid ZA (2016a) Exoelectrogens: recent advances in molecular drivers involved in extracellular electron transfer and strategies used to improve it for microbial fuel cell applications. Renew Sust Energ Rev 56:1322–1336. https://doi.org/10.1016/j.rser.2015.12.029

Kumar R, Singh L, Zularisam AW et al (2016b) Potential of porous Co3O4 nanorods as cathode catalyst for oxygen reduction reaction in microbial fuel cells. Bioresour Technol 220:537–542. https://doi.org/10.1016/j.biortech.2016.09.003

Lee M, Kondaveeti S, Jeon T et al (2020) Influence of humidity on performance of single chamber air-cathode microbial fuel cells with different separators. PRO 8. https://doi.org/10.3390/pr8070861

Logan BE, Regan JM (2006) Electricity producing bacterial communities in microbial fuel cells. Trends Microbiol 14(12):512–518. https://doi.org/10.1016/j.tim.2006.10.003

Lovley DR (2006) Bug juice: harvesting electricity with microorganisms. Nat Rev Microbiol 4:497–508. https://doi.org/10.1038/nrmicro1442

Moat AG, Foster JW, Spector MP (eds) (2002) Microbial physiology, 4th edn. Wiley, New York

Mulyadi, Arsianti RW (2018) Low power electrical generator from soil microbial fuel cell. 2018 Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS). https://doi.org/10.1109/EECCIS.2018.8692948

Nicholls DG (1982) Bioenergetics – an introduction to the chemiosmotic theory. Academic Press, London

Potter M (1911) Electrical effects accompanying the decomposition of organic compounds. Proc R Soc Lond B 84:260–276. https://doi.org/10.1098/rspb.1911.0073

Rabaey K, Boon N, Siciliano D et al (2004) Biofuel cells select for microbial consortia that self-mediate electron transfer. Appl Environ Microbiol 70(9):5373–5382. https://doi.org/10.1128/AEM.70.9.5373-5382.2004

Reguera G, Nevin KP, Nicoll JS et al (2006) Biofilm and nanowire production leads to increased current in *Geobacter sulfurreducens* fuel cells. Appl Environ Microbiol 72(11):7345–7348. https://doi.org/10.1128/AEM.01444-06

Ren L, Ahn Y, Logan BE (2014) A two-stage microbial fuel cell and anaerobic fluidized bed membrane bioreactor (MFC-AFMBR) system for effective domestic wastewater treatment. Environ Sci Technol 48(7):4199–4206. https://doi.org/10.1021/es500737m

Sedighi M, Aljlil SA, Alsubei MD et al (2018) Performance optimisation of microbial fuel cell for wastewater treatment and sustainable clean energy generation using response surface methodology. Alex Eng J 57(4):4243–4253. https://doi.org/10.1016/j.aej.2018.02.012

Shantaram A, Beyenal H, Veluchamy R et al (2005) Wireless sensors powered by microbial fuel cells. Environ Sci Technol 39:5037–5042. https://doi.org/10.1021/es0480668

Shukla A, Suresh P, Berchmans S et al (2004) Biological fuel cells and their applications. Curr Sci 87:455–468

Truong VM, Duong NB, Wang CL et al (2019) Effects of cell temperature and reactant humidification on anion exchange membrane fuel cells. Materials (Basel) 12(13):2048. https://doi.org/10.3390/ma12132048

Yangyue J, Xu Y, Yang Q et al (2014) Power generation using polyaniline/multi-walled carbon nanotubes as an alternative cathode catalyst in microbial fuel cells. Int J Energy Res 38:1416–1423. https://doi.org/10.1002/er.3155

Yong XY, Feng J, Chen YL et al (2014) Enhancement of bioelectricity generation by cofactor manipulation in microbial fuel cell. Biosens Bioelectron 56:19–25. https://doi.org/10.1016/j.bios.2013.12.058

Wetser K, Sudirjo E, Buisman CJN et al (2015) Electricity generation by a plant microbial fuel cell with an integrated oxygen reducing biocathode. Appl Energy 137:151–157. https://doi.org/10.1016/j.apenergy.2014.10.006