

Construction of single chamber microbial fuel cell for bio-energy generation: A review

Saheli Khan, Roma Roy, Arnab Gon, Riya Pajiyar, Manjarima Ganguli and Jigisha Roy Panda *

Guru Nanak Institute of Pharmaceutical Science and Technology 157/F, Nilgunj Road, Sahid Colony, Panihati, Khardaha, Kolkata – 700114, West Bengal, India.

World Journal of Biology Pharmacy and Health Sciences, 2026, 25(02), 207-215

Publication history: Received on 28 April 2025; revised on 31 January 2026; accepted on 03 February 2026

Article DOI: <https://doi.org/10.30574/wjbphs.2026.25.2.0567>

Abstract

The Microbial Fuel Cell is a bio-electrochemical process that produces energy or electricity from different chemical compounds, such as waste material like food waste, agricultural residues, and various industrial and domestic wastewater stream by the action of microorganisms. Mainly MFCs are designed as two-chambered, but here it is aimed to demonstrate the utility of Single Chambered MFC (SCMFC) for producing energy. In this SCMFC, both the cathode and anode chamber are reported to be constructed, to produce energy by reducing the complexity of the construction with low-cost material. Even this SCMFC construction produces energy at low temperatures. In recent studies it is known that reproducible cycles of power generation could be achieved at the two lowest temperatures of 4°C and 10°C, and production increases linearly with temperature. Using bamboo charcoal as an anode, it was noticed that production was maximum with a current density of about $3.27 \times 10^{-3} \text{ mW/m}^2$ with one MFC chamber. In the systems, electrochemical microorganisms were oxidized with the chemical compound and released electrons in the anode chamber, and the reduction of the oxygen through the circuit was also observed.

Keyword: Electrochemically active microorganisms; Single chambered Microbial Fuel Cell; Bioenergy; Current; Green-energy

1. Introduction

In recent news, the minerals are gradually reduced in our society. So, in the future, it will become challenging to produce energy from minerals. Nowadays, the whole society cannot even imagine living without energy or electricity; in simple words, our society has become energy-based society to cope with the technological advancements.^[1,2] In our environment, there are lots of different waste materials around us that are pollutants to nature. Recent studies that work on waste materials and generate energy or electricity. These energies are totally eco-friendly, which helps us. The energy is produced through the help of microorganisms that degrade the materials and generate energy. In the scientific way, this process is known as Microbial Fuel Cell (MFC).^[3] MFC is a bio-electrochemical system where organic matters are converted from chemical energy into electric energy at the presence of microorganisms with the metabolic reactions. It is a one of the closed systems, non-combusting device where energy is generated without burning^[4-6]. In our nature there are various types of microbes which are particularly and specifically responsible to degrade wastes. Different types of MFC chambers are found to be single chambered MFC(SCMFC) and double chambered MFC(DCMFC)^[7]. MFCs have separate anode and cathode chambers, and a physical barrier that consists two distinct chambers. It is common to construct MFC, the anode part is responsible for break-down of waste material or organic matter where microorganisms are present as biocatalysts. In the simple words, the wastes materials are used as the feed of microorganisms. Single camber and double chamber MFC have a major difference, in DCMFC have two separate chambers for anode and cathode. But in SCMFC there is no separated chamber like DCMFC.^[9]

* Corresponding author: Jigisha Roy Panda

Table 1 Difference between SCMFC & DCMFC [10–12]

Title	SCMFC	DCMFC
Configuration	Anode and cathode are present in a same compartment.	Anode and cathode are present in separate compartment.
Membrane	It has no separating membrane.	It has a proton exchange membrane.
Oxygen diffusion	Higher rate of oxygen diffused that can result in lower efficiency due to competition between microbes and oxygen.	Here, controlling the rate of oxygen level is necessary because of separate chamber.
Operational conditions	Moreover, neutral pH is responsible for microbial growth.	Expresses varying pH due to microbial different metabolic activity in each chamber.
Current production	Competitively lower output than DCMFC.	Generally, gives higher output.

2. Materials and methods

In single chamber, anode and cathode parts are not separated, hence there is no proton exchange membrane. It a simple design or construction of MFC. Detailed construction is described below –

2.1. Chamber Design

The chamber is mainly single cylindrical, where both anode and cathode are present. It is a simpler construction than DCMFC, and it is made up of this chamber and different types of materials, like PVC, Plexiglas, etc. [13] Through some studies it is known that proton exchange membrane (PEM) can either be present or absent.

Table 2 Short description of anode & cathode and their mode of action

Anode	Conductive materials are mainly used for attachment of microbes which is its suitable area and through the activity of metabolic reaction it produces electrons. Carbon cloth, bamboo charcoal, graphite etc are used as anodic electrodes. [10,12]
Cathode	Cathode mainly accepts the electron and transfers it in the air. It reduces the oxygen in water by the use of catalyst like Platinum. [13,14]

In the surface of electrodes, microorganisms form biofilms that help to generate energy and convert organic to chemical reaction. (Fig1)

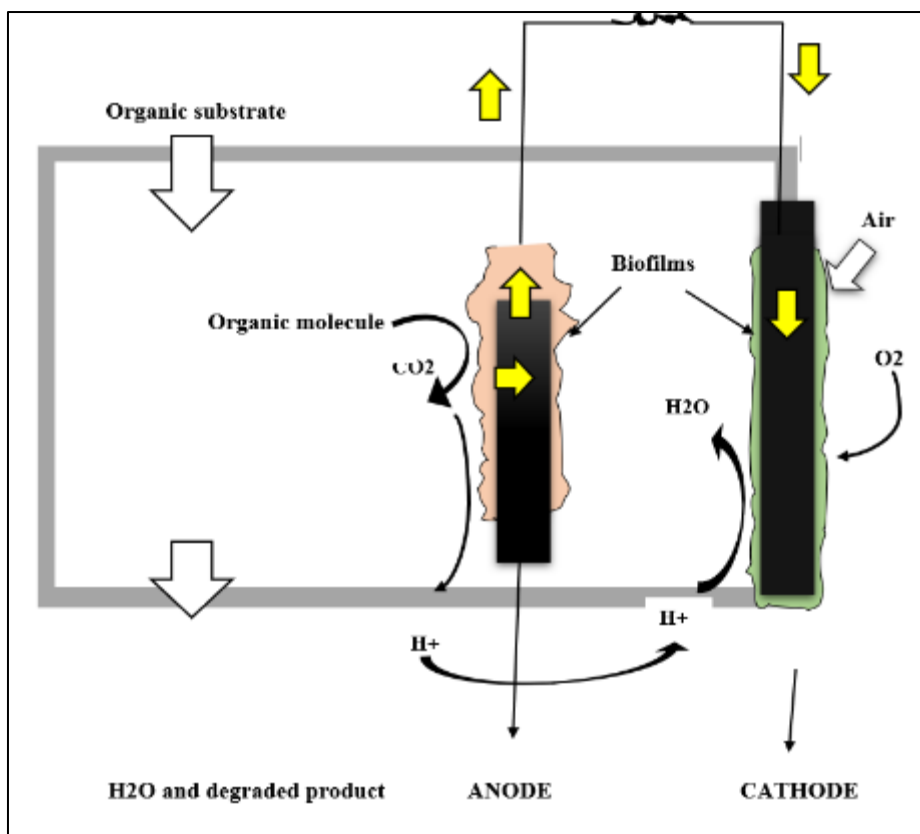


Figure 1 A raw diagram of Single Chamber Microbial Fuel Cell

2.2. Inoculation

In this system, various types of microorganisms are present, like bacteria, algae, etc., which break down the organic matter and produce electrons ^[15]. Some of microbes' example and their function mentioned at the below:

Table 3 Categories some electrochemilly active bacteria strains with theirs functions

Microorganism	Function
<i>Geobacter sp.</i>	Some studies show that a species of <i>Geobacter</i> is a common good exoelectrogenes which oxidize easily organic substrate and produced electric current in SCMFC. Example – <i>Geobacter sulfurreducens</i> ^[16–18]
<i>Bacillus sp.</i>	A paper demonstrated that <i>Bacillus subtilis</i> which utilize carbon source like glucose and electron acceptor such as nitrate in SCMFC. ^[10]
<i>Shewanilla sp.</i>	It is similar to <i>Geobacter sp.</i> , have a particular species that is <i>Shewanilla putrefaciens</i> . Can reduce different electron acceptor such as metal ion. ^[19]
Other anaerobic bacteria	Some research described that anaerobic bacteria also help in degradation of organic matter in SCMFC through fermentation processes. Example – <i>Clostridium botulinum</i> , <i>Bacteroides fragilies</i> , <i>Lactobacillus sp.</i> etc ^[20]

2.3. Mode of action of SCMFC

It is a simple construction and has a common mode of action^[21–24] like –

2.3.1. Microbial metabolisms

Through the microbial metabolism, microbes break down the organic matter and released electron.

2.3.2. Anodic reaction

Here microbes oxidize the organic matter and electron transfer to the anode. The reaction like -



2.3.3. Electron transfer

Through the external circuit electron transfer to the cathode and produce electron.

2.3.4. Cathodic reaction

Cathode capture the electron and generate the reduction reaction, involved oxygen form the air. The reaction like-

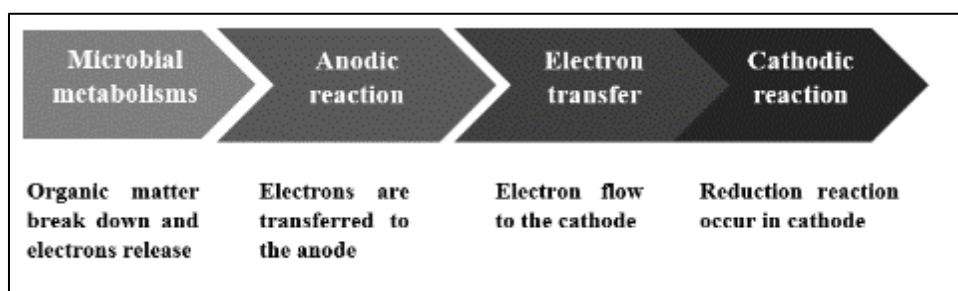
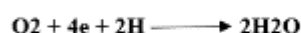


Figure 2 Step of mode of action of SCMFC

3. Results and discussion

Various factors are responsible for performances of Single chamber MFC which determined how much degrade organic matter and produced current. The major factor which are responsible that are-

3.1. Substrate type

Production of output depend on the concentration of substrate. Glucose, acetate and wastewater used as substrate.^[25]

Table 4 Using substrates and their mode of action

Substrate	Mode of action
Glucose	It is simple carbon source of nutrient of microbes that typically produce high rate of energy. A research show that, in SCMFC generate 693mV open circuit voltage. ^[25,26]
Wastewater	Wastewater is most valuable substrate which used in SCMFC where have present most of organic matter and polluted agent. These degraded by microbial community and generated current. ^[27,28]

A report demonstrated that when glucose used as substrate, power densities about 52 mW/m² but when acetate and butyrate used as substrate that have shown high output then glucose.^[26]

3.2. Electrodes material

For transformation of electron, electrodes material played vital role in SCMFC.

Table 5 Some conditions and their functions

Conditions	Function
Surface area	Flat and large surface is good for system, where microbes are easily attaching to the surface that's why more microbes more energy produced. ^[29]
Conductivity	Good and high-quality conductivity used in SCMFC for high much electron production. Used as Carbon cloth, Carbon nanotubes, Graphene etc. ^[27]

3.3. Operational parameter

Temperature, pH, external resistant play important role in SCMFC.

Table 6 Dependent variables and their roles

Depending factor	Function
Temperature	Studies indicate that temperature can influence total output of the system like voltage, current generation. Mesophilic temperature is best for SCMFC. ^[30]
Ph level	In SCMFC, for microbial activity and energy generation, neutral pH is favourable condition. ^[27]
External resistant	It is very important to maintain the current density and effect the output of the system. ^[25,31]

Table 7 Types of organic matter degraded

Organic matter	Analysis
Domestic organic matter	Studies indicate that domestic organic matters are degraded through the SCMFC and produced electric energy. Some bacteria like <i>Pseudomonas aeruginosa</i> , <i>Actinobacter schindleri</i> that help to degradation of the household waste materials. ^[32]
Agricultural matter	Studies indicate that raw corn is valuable effective degradation product which produced good energy with the help of microbes. But output energy depends on the operational factor and microbial community. ^[33]
Wastewater	Research shows that to the help of microbial community and anodic reaction make a better wastewater treatment plan. In wastewater, there have lots of organic matter present that can't be easily degraded. But degraded by the SCMFC such as Ammonia, Bisphenol. Although, in wastewater, SCMFC continuously monitor Biological Oxygen Demand (BOD) and generate electric energy. ^[27]
Volatile organic matter	Some paper describes current generate by the degradation of volatile organic matter. ^[33,34]

3.4. Current production

Depending on the various factor Single chamber Microbial Fuel Cell generated different value of current or current density^[35,36]. Though some paper reported that DCMFC produce more energy than SCMFC, but SCMFC generate electricity or energy at very low temperature like 4° centigrade and production also increased gradually with temperature.^[37]

Table 8 Analysis output energy

Current output examples	An SCMFC, under the open circuit condition produced maximum current output about 960 ± 50 mA and other operation condition or different configuration generate 672 ± 35 mA. Through another experiment report get to know, power density of 494 ± 21 mW/m ² generate about 0.86 mA. ^[9,38]
Power density and current density	One report shows that using bamboo charcoal as anode and produced maximum current density about 3.27×10^3 mW/m ² with one MFC chamber but when three MFC are joined then decrease about 1.14×10^3 mW/m ² . Through this result, demonstrated that if increase the internal resistance then decrease the power density. ^[9,39,40]
Substrate utilizing	Under optimal conditions use substrate such as food waste increased current density and report indicate the value about 4.388 A/cm ² ^[9,41-43] .

4. Applications & Advantages

SCMFC degraded organic matter and produced electric energy. So, it has some advantages and applications. ^[44-47] Some applications and advantages of SCMFC : Water treatment, electricity generation, biosensor and byproduct recovery, heavy metal recovery, sanitation.

Some advantages of SCMFC:

- Overall design is simpler than dual chamber MFC.
- Lower internal resistance gave higher power output.
- This system can freely uptake oxygen from the air that's why it facilitated to enhanced oxygen reduction and have some environmental benefits such as pollution free energy.

5. Conclusion

The SCMFC experiments are going on only in small scale process but would not grow up in large scale process. So, it is a big research gap, if it is going on large scale process then generated high energy which is green energy and helpful for our environment because SCMFC degraded organic matter and produced electric energy.

Compliance with ethical standards

Acknowledgement

The authors are sincerely thankful to the honorable Director Prof. (Dr.) Abhijit Sengupta, respected Principal Prof. (Dr.) Lopamudra Datta and the Head of Department Dr. Swati Chakraborty for providing resources to carry out for this review work.

Disclosure of conflict of interest

The authors declare no conflict of interest with anyone.

References

- [1] Graedel, T. E., Harper, E. M., Nassar, N. T., Nuss, P., & Reck, B. K. (2015). Criticality of metals and metalloids. Proceedings of the National Academy of Sciences, 112(14), 4257-4262. <https://doi.org/10.1073/pnas.1500415112>
- [2] Graedel, T. E., Harper, E. M., Nassar, N. T., & Reck, B. K. (2015). On the materials basis of modern society. Proceedings of the National Academy of Sciences, 112(20), 6295-6300. <https://doi.org/10.1073/pnas.1312752110>

- [3] Fadzli, F. S., Bhawani, S. A., & Adam Mohammad, R. E. (2021). Microbial Fuel Cell: Recent Developments in Organic Substrate Use and Bacterial Electrode Interaction. *Journal of Chemistry*, 2021, 1–16. <https://doi.org/10.1155/2021/4570388>
- [4] Yang, X.-G., Wen, P.-P., Yang, Y.-F., Jia, P.-P., Li, W.-G., & Pei, D.-S. (2023). Plastic biodegradation by in vitro environmental microorganisms and in vivo gut microorganisms of insects. *Frontiers in Microbiology*, 13. <https://doi.org/10.3389/fmicb.2022.1001750>
- [5] Tamboli, E., & Eswari, J. S. (2019). Microbial Fuel Cell Configurations. In *Microbial Electrochemical Technology* (pp. 407–435). Elsevier. <https://doi.org/10.1016/B978-0-444-64052-9.00016-9>
- [6] Deval, A., & Dikshit, A. K. (2013). Construction, Working and Standardization of Microbial Fuel Cell. *APCBEE Procedia*, 5, 59–63. <https://doi.org/10.1016/j.apcb.2013.05.011>
- [7] Saravanan, N., & Karthikeyan, M. (2017). STUDY OF SINGLE CHAMBER AND DOUBLE CHAMBER EFFICIENCY AND LOSSES OF WASTEWATER TREATMENT. *International Research Journal of Engineering and Technology*. www.irjet.net
- [8] Pal, J., & Kumar, N. (2017). Comparative Study on single and double chambered Microbial Fuel Cell. <http://www.sedindia.org>
- [9] Sato, C., Paucar, N. E., Chiu, S., Mahmud, M. Z. I. M., & Dudgeon, J. (2021). Single-Chamber Microbial Fuel Cell with Multiple Plates of Bamboo Charcoal Anode: Performance Evaluation. *Processes*, 9(12), 2194. <https://doi.org/10.3390/pr9122194>
- [10] Nimje, V. R., Chen, C.-C., Chen, H.-R., Chen, C.-Y., Tseng, M.-J., Cheng, K.-C., Shih, R.-C., & Chang, Y.-F. (2012). A Single-Chamber Microbial Fuel Cell without an Air Cathode. *International Journal of Molecular Sciences*, 13(3), 3933–3948. <https://doi.org/10.3390/ijms13033933>
- [11] Patra, A. (2008). Low-Cost, Single-Chambered Microbial Fuel Cells for Harvesting Energy and Cleansing Wastewater. *Journal of the U.S. SJWP*. <https://doi.org/10.2175/SJWP>
- [12] Park, Y., Yu, J., Nguyen, V. K., Park, S., Kim, J., & Lee, T. (2021). Understanding complete ammonium removal mechanism in single-chamber microbial fuel cells based on microbial ecology. *Science of The Total Environment*, 764, 144231. <https://doi.org/10.1016/j.scitotenv.2020.144231>
- [13] Roy, H., Rahman, T. U., Tasnim, N., Arju, J., Rafid, Md. M., Islam, Md. R., Pervez, Md. N., Cai, Y., Naddeo, V., & Islam, Md. S. (2023). Microbial Fuel Cell Construction Features and Application for Sustainable Wastewater Treatment. *Membranes*, 13(5), 490. <https://doi.org/10.3390/membranes13050490>
- [14] Costa de Oliveira, M. A., D'Epifanio, A., Ohnuki, H., & Mecheri, B. (2020). Platinum Group Metal-Free Catalysts for Oxygen Reduction Reaction: Applications in Microbial Fuel Cells. *Catalysts*, 10(5), 475. <https://doi.org/10.3390/catal10050475>
- [15] Rabaey, K., Read, S. T., Clauwaert, P., Freguia, S., Bond, P. L., Blackall, L. L., & Keller, J. (2008). Cathodic oxygen reduction catalyzed by bacteria in microbial fuel cells. *The ISME Journal*, 2(5), 519–527. <https://doi.org/10.1038/ismej.2008.1>
- [16] Lovley, D. R., Ueki, T., Zhang, T., Malvankar, N. S., Shrestha, P. M., Flanagan, K. A., Aklujkar, M., Butler, J. E., Giloteaux, L., Rotaru, A.-E., Holmes, D. E., Franks, A. E., Orellana, R., Risso, C., & Nevin, K. P. (2011). *Geobacter* (pp. 1–100). <https://doi.org/10.1016/B978-0-12-387661-4.00004-5>
- [17] Sreelekshmy, B. R. (2020). Exploration of Electrochemically Active Bacterial Strains for Microbial Fuel Cells: An Innovation in Bioelectricity Generation. *Journal of Pure and Applied Microbiology*, 14(1), 103–122. <https://doi.org/10.22207/JPAM.14.1.12>
- [18] Feng, C., Li, J., Qin, D., Chen, L., Zhao, F., Chen, S., Hu, H., & Yu, C.-P. (2014). Characterization of Exoelectrogenic Bacteria *Enterobacter* Strains Isolated from a Microbial Fuel Cell Exposed to Copper Shock Load. *PLoS ONE*, 9(11), e113379. <https://doi.org/10.1371/journal.pone.0113379>
- [19] Yu, K., Huang, Z., Xiao, Y., & Wang, D. (2022). *Shewanella* infection in humans: Epidemiology, clinical features and pathogenicity. *Virulence*, 13(1), 1515–1532. <https://doi.org/10.1080/21505594.2022.2117831>
- [20] Ahmed, S., Rozaik, E., & Abdel-Halim, H. (2016). Performance of single-chamber microbial fuel cells using different carbohydrate-rich wastewaters and different inocula. *Polish Journal of Environmental Studies*, 25(2), 503–510. <https://doi.org/10.15244/pjoes/61115>

- [21] Logroño, W., Pérez, M., Urquiza, G., Kadier, A., Echeverría, M., Recalde, C., & Rákhely, G. (2017). Single chamber microbial fuel cell (SCMFC) with a cathodic microalgal biofilm: A preliminary assessment of the generation of bioelectricity and biodegradation of real dye textile wastewater. *Chemosphere*, 176, 378–388. <https://doi.org/10.1016/j.chemosphere.2017.02.099>
- [22] Santoro, C., Serov, A., Villarrubia, C. W. N., Stariha, S., Babanova, S., Artyushkova, K., Schuler, A. J., & Atanassov, P. (2015). High catalytic activity and pollutants resistivity using Fe-AAPyr cathode catalyst for microbial fuel cell application. *Scientific Reports*, 5. <https://doi.org/10.1038/srep16596>
- [23] Yang, S., Xiao, N., Wang, J., Zhang, B., & Huang, J. J. (2022). Development of miniature self-powered single-chamber microbial fuel cell and its response mechanism to copper ions in high and trace concentration. *Science of The Total Environment*, 834, 155367. <https://doi.org/10.1016/j.scitotenv.2022.155367>
- [24] Suphannarach, S., Thanapatay, D., Prasertsung, N., & Kamuang, S. (2023). Electricity Generation from Single Chamber Microbial Fuel Cells using Granular Activated Carbon as Anode for Wastewater Treatment. *Engineering Journal*, 27(6), 1–10. <https://doi.org/10.4186/ej.2023.27.6.1>
- [25] Karamzadeh, M., Kadivar, M., Mahmoodi, P., Asefi, S. S., & Taghipour, A. (2023). Modeling and experimental investigation of the effect of carbon source on the performance of tubular microbial fuel cell. *Scientific Reports*, 13(1). <https://doi.org/10.1038/s41598-023-38215-5>
- [26] Apollon, W. (2023). An Overview of Microbial Fuel Cell Technology for Sustainable Electricity Production. *Membranes*, 13(11), 884. <https://doi.org/10.3390/membranes13110884>
- [27] Yao, H., Xiao, J., & Tang, X. (2023). Microbial Fuel Cell-Based Organic Matter Sensors: Principles, Structures and Applications. *Bioengineering*, 10(8), 886. <https://doi.org/10.3390/bioengineering10080886>
- [28] Liu, W., Cheng, S., Sun, D., Huang, H., Chen, J., & Cen, K. (2015). Inhibition of microbial growth on air cathodes of single chamber microbial fuel cells by incorporating enrofloxacin into the catalyst layer. *Biosensors and Bioelectronics*, 72, 44–50. <https://doi.org/10.1016/j.bios.2015.04.082>
- [29] Sonawane, J. M., Adeloju, S. B., & Ghosh, P. C. (2017). Landfill leachate: A promising substrate for microbial fuel cells. *International Journal of Hydrogen Energy*, 42(37), 23794–23798. <https://doi.org/10.1016/j.ijhydene.2017.03.137>
- [30] Khan, N., Khan, M. D., Nizami, A.-S., Rehan, M., Shaida, A., Ahmad, A., & Khan, M. Z. (2018). Energy generation through bioelectrochemical degradation of pentachlorophenol in microbial fuel cell. *RSC Advances*, 8(37), 20726–20736. <https://doi.org/10.1039/C8RA01643G>
- [31] Wang, Z., Mahadevan, G. D., Wu, Y., & Zhao, F. (2017). Progress of air-breathing cathode in microbial fuel cells. *Journal of Power Sources*, 356, 245–255. <https://doi.org/10.1016/j.jpowsour.2017.02.004>
- [32] Yaakop, A. S., Ahmad, A., Hussain, F., Oh, S.-E., Alshammari, M. B., & Chauhan, R. (2023). Domestic Organic Waste: A Potential Source to Produce the Energy via a Single-Chamber Microbial Fuel Cell. *International Journal of Chemical Engineering*, 2023, 1–10. <https://doi.org/10.1155/2023/2425735>
- [33] Wu, S., Qiao, Y., Jiang, K., He, Y., Guo, S., & Zhou, H. (2018). Tailoring Sodium Anodes for Stable Sodium–Oxygen Batteries. *Advanced Functional Materials*, 28(13). <https://doi.org/10.1002/adfm.201706374>
- [34] Kaparaju, P., Serrano, M., Thomsen, A. B., Kongjan, P., & Angelidaki, I. (2009). Bioethanol, biohydrogen and biogas production from wheat straw in a biorefinery concept. *Bioresource Technology*, 100(9), 2562–2568. <https://doi.org/10.1016/j.biortech.2008.11.011>
- [35] Huang, L., & Logan, B. E. (2008). Electricity generation and treatment of paper recycling wastewater using a microbial fuel cell. *Applied Microbiology and Biotechnology*, 80(2), 349–355. <https://doi.org/10.1007/s00253-008-1546-7>
- [36] Khalid, S., Alvi, F., Fatima, M., Aslam, M., Riaz, S., Farooq, R., & Zhang, Y. (2018). Dye degradation and electricity generation using microbial fuel cell with graphene oxide modified anode. *Materials Letters*, 220, 272–276. <https://doi.org/10.1016/j.matlet.2018.03.054>
- [37] Khan, S. S., Amjad, M., Shareef, H., & Larkin, S. (2024). Review of microbial fuel cell from a techno-economic perspective. *Energy Exploration & Exploitation*, 42(1), 373–398. <https://doi.org/10.1177/01445987231208510>
- [38] Guo, Z., Cao, J., Xu, R., Zhang, H., He, L., Gao, H., Zhu, L., Jia, M., Yang, Z., & Xiong, W. (2024). Novel Photoelectron-Assisted Microbial Reduction of Arsenate Driven by Photosensitive Dissolved Organic Matter in Mine Stream

Sediments. *Environmental Science & Technology*, 58(50), 22170–22182. <https://doi.org/10.1021/acs.est.4c09647>

- [39] Martínez-Conesa, E. J., Ortiz-Martínez, V. M., Salar-García, M. J., de Los Ríos, A. P., Hernández-Fernández, F. J., Lozano, L. J., & Godínez, C. (2017). A Box–Behnken Design-Based Model for Predicting Power Performance in Microbial Fuel Cells Using Wastewater. *Chemical Engineering Communications*, 204(1), 97–104. <https://doi.org/10.1080/00986445.2016.1236336>
- [40] Min, B., Cheng, S., & Logan, B. E. (2005). Electricity generation using membrane and salt bridge microbial fuel cells. *Water Research*, 39(9), 1675–1686. <https://doi.org/10.1016/j.watres.2005.02.002>
- [41] Rojas-Flores, S., de La Cruz-Noriega, M., Cabanillas-Chirinos, L., Benites, S. M., Nazario-Naveda, R., Delfín-Narciso, D., Gallozzo-Cardenas, M., Diaz, F., Murga-Torres, E., & Rojas-Villacorta, W. (2023). Green Energy Generated in Single-Chamber Microbial Fuel Cells Using Tomato Waste. *Sustainability*, 15(13), 10461. <https://doi.org/10.3390/su151310461>
- [42] Koo, B., Lee, S.-M., Oh, S.-E., Kim, E. J., Hwang, Y., Seo, D., Kim, J. Y., Kahng, Y. H., Lee, Y. W., Chung, S.-Y., Kim, S.-J., Park, J. H., & Jung, S. P. (2019). Addition of reduced graphene oxide to an activated-carbon cathode increases electrical power generation of a microbial fuel cell by enhancing cathodic performance. *Electrochimica Acta*, 297, 613–622. <https://doi.org/10.1016/j.electacta.2018.12.024>
- [43] Yaqoob, A. A., Serrà, A., Ibrahim, M. N. M., & Yaakop, A. S. (2021). Self-assembled oil palm biomass-derived modified graphene oxide anode: An efficient medium for energy transportation and bioremediating Cd (II) via microbial fuel cells. *Arabian Journal of Chemistry*, 14(5), 103121. <https://doi.org/10.1016/j.arabjc.2021.103121>
- [44] Yaqoob, A. A., Serrà, A., Ibrahim, M. N. M., & Yaakop, A. S. (2021). Self-assembled oil palm biomass-derived modified graphene oxide anode: An efficient medium for energy transportation and bioremediating Cd (II) via microbial fuel cells. *Arabian Journal of Chemistry*, 14(5), 103121. <https://doi.org/10.1016/j.arabjc.2021.103121>
- [45] Bergel, A., Féron, D., & Mollica, A. (2005). Catalysis of oxygen reduction in PEM fuel cell by seawater biofilm. *Electrochemistry Communications*, 7(9), 900–904. <https://doi.org/10.1016/j.elecom.2005.06.006>
- [46] Chang, I. S., Jang, J. K., Gil, G. C., Kim, M., Kim, H. J., Cho, B. W., & Kim, B. H. (2004). Continuous determination of biochemical oxygen demand using microbial fuel cell type biosensor. *Biosensors and Bioelectronics*, 19(6), 607–613. [https://doi.org/10.1016/S0956-5663\(03\)00272-0](https://doi.org/10.1016/S0956-5663(03)00272-0)
- [47] Bullen, R. A., Arnot, T. C., Lakeman, J. B., & Walsh, F. C. (2006). Biofuel cells and their development. *Biosensors and Bioelectronics*, 21(11), 2015–2045. <https://doi.org/10.1016/j.bios.2006.01.030>