# UTILISATION OF GREEN WASTE FROM MINE OVERBURDEN THROUGH BIO-ELECTROCHEMICAL SYSTEMS

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**ABSTRACT.** Proper management of overburden materials can reduce the environmental impact and increase the benefits of mining activities. It is important to consider the specific composition of the overburden and local needs when selecting the most appropriate recovery method. And while much of the overburden material can be used in construction, reclamation, cement production and more, the green waste problem has not been sufficiently solved. In the present publication, the possibilities of generating energy from the green waste from the overburden through bio-electrochemical systems are investigated. The possibilities of generating energy from grass, wood chips and leaves have been studied. The best results were achieved in grass utilisation, generating a power density of 107,58 mW/m$^2$.

**Key words:** mine overburden, bio-electrochemical systems, solid phase microbial fuel cells

## Introduction

Mining of mineral ore requires the removal of an earth mass. Especially in open pit mining, the volume of overburden generated during ore extraction can be very high. An overburden is a layer of soil, vegetation, and rock mass that must be removed to reach the ore being mined. Unlike the tailings, the overburden in most cases does not contain toxic components (Adibi et al., 2013).

The overburden material often finds direct application as sub-ballast in railway tracks, underlayment for asphalt pavements, aggregates (Mahamaya and Das, 2017), reclamation of terrains (Jambhulkar and Kumar, 2019) and others. Apart from these applications that only focused on the direct use of mine overburden in various fields, overburden materials offer a high potential for conversion into a value-added product (Adibi et al., 2013).

In addition to soil and rock mass, the mine overburden also contains a large amount of vegetation. And unlike the mineral part of the overburden, the problem with the utilisation of green waste has not been solved to a sufficient extent (Spargo et al. 2016). Green waste is plant-based organic material typically generated from lawn clippings, cut branches, fallen trees, leaves, plants, soil and mulch. Green waste typically contains seeds, weeds and invasive plants that can enter and disrupt other ecosystems if disposed of inappropriately. These plants compete with native plants and degrade habitat quality, impacting biodiversity. Large piles of green waste can also suffocate small native plants and ground covers, affecting wildlife that relies on them for food and shelter. As green waste dries out, it creates a fire hazard, endangering neighbouring properties, infrastructure and the environment. Green waste dumped into rivers or stormwater ditches affects water quality. Decomposition of organic material consumes oxygen and releases nutrients, which can lead to aquatic eutrophication and disruption of aquatic ecosystems. Green waste disposed of in this way can clog sewers and contribute to localised flooding (Smith and Aber, 2018). Piles of green waste threaten the landscape and affect the values and amenities of natural areas. The material can also serve as a breeding ground for pests. The costs associated with the removal and disposal of green waste could also be a significant issue (Chiu et al., 2016).

Recently, renewable bioenergy has been seen as one of the ways to ease future fuel needs and overcome the global warming crisis. Microbial fuel cell (MFC)-assisted bioelectricity generation through the degradation of organic matter has attracted considerable interest in both fundamental and applied research in recent years (Utomo et al., 2017). Bio-electrochemical systems (BESs) include several types of technologies, mainly microbial electrolysis cells (MEC), microbial fuel cells (MFC), microbial solar cells (MSC), and microbial desalination cells (MDC) (Wang et al., 2024). Generation of value-added products from negative value organic waste using BES is a sustainable approach that simultaneously addresses green waste management and resource recovery. Among the various types of bio-electrochemical systems, MFCs are the most frequently used for resource recovery from solid-phase organic wastes (Addaga et al., 2023).

A microbial fuel cell (MFC) is a device that uses bacteria to directly convert chemical energy stored in organic matter into electricity through electrochemical processes. MFCs can be fed with liquid-phase substrates such as domestic wastewater and industrial wastewater. Solid-phase microbial fuel cells (SPMFCs) can be fuelled with solid-phase organic wastes such as sludge, sediments and vegetation (Song and Aber, 2018). In this configuration, the cathode is usually exposed to the ambient oxygen in the air or immersed in water, while the anode is placed under anaerobic conditions in the solid-phase organic matter at the bottom of the cell (Figure 1).

One of the most important key aspects of MFC technology is the mechanism used by microorganisms to adhere to the electrode surface and the subsequent electron transfer which is carried out. The main electron transfer mechanisms are two - direct electron transfer (DET) and mediated electron transfer (MET). The most commonly used electroactive microorganisms in bio-electrochemical systems are *Shewanella, Geobacter, Oscillatoria, Pseudomonas*, etc. (Mahmoud et al., 2022).

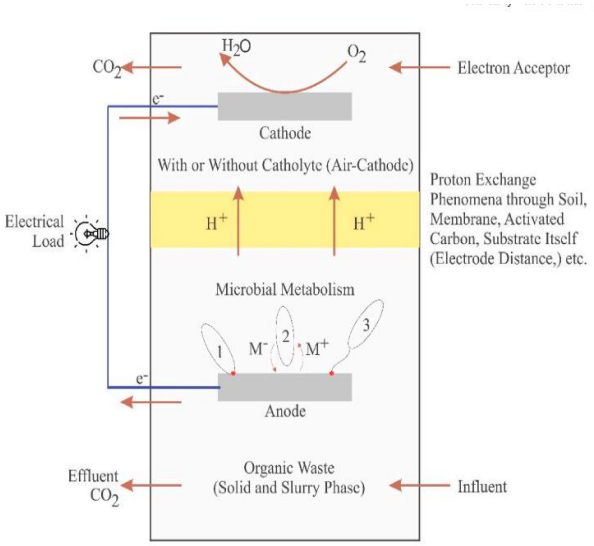



**Fig. 1. Schematic illustration of the solid phase microbial fuel cells process (Mochamad et al., 2021)**

The bio-anode combines the anode and the biofilm - a working electrode for the substrate oxidation process. Studies have shown that a high current density is produced inside the anodes, since most of the biomass remains attached to the electrode. Similarly, a reduction reaction occurs at the cathode where electrons and protons react with reagents producing hydrogen or other products (Debnath and Dutta, 2023).

SPMFCs can be used as power sources for long-term environmental monitoring devices due to their simple design and solid organic matter providing a long-term power source (Venkata and Chandrasekhar, 2011).

Biodegradable organic matter present in green waste can be efficiently used to generate energy in the form of bioelectricity by utilisation in solid phase microbial fuel cells. If properly designed, a SPMFC can facilitate the direct conversion of solid waste to energy and therefore make the process sustainable for waste management and recovery (Logrono et al., 2015).

In recent years, SPMFCs have emerged as a promising but challenging waste-to-energy technology, besides their treatment, gaining increasing importance due to their sustainable nature. This process offers the dual benefits of waste treatment and providing access to cheap and environmentally friendly energy (Mochamad et al., 2021).

This research aims to optimise the use of mine overburden waste by transforming it into value-added products and ensuring comprehensive and sustainable utilisation of green overburden waste.

## Materials and methods

### Construction of solid phase microbial fuel cell

The construction of the bio-electrochemical system for the experiment shown in Figure 2 is based on a single-chamber solid phase microbial fuel cell .

The solid phase microbial fuel cell is a plastic container with a volume of 800 $cm^3$. A graphite electrode with an area of 30 $cm^2$ is placed at the bottom of the vessel. The vessel was filled with organic green waste with a volume of 600 $cm^3$. The cell was then filled with pure water and a second 30 $cm^2$ graphite electrode was placed in the surface layer of the water.

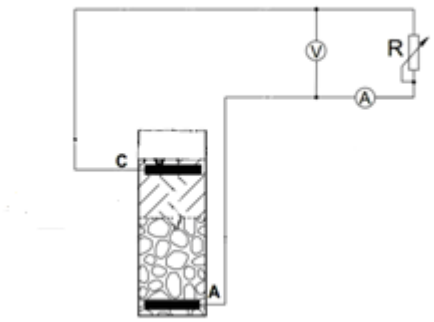



**Fig. 2. Solid phase microbial fuel cell schematic diagram A – anode, C - cathode**

Graphite electrodes were chosen due to their higher porosity and specific surface area, an advantage for the adherence and growth of electroactive microorganisms.

### Solid phase waste matter composition

Three identical solid phase microbial fuel cells were made. The first one was filled with grass (*Cynodon dactylon*), the second was filled with leaves (*Prunus cerasifera*) and the third was filled with shredded wood (wood chips) (*Prunus cerasifera)*. 50 $cm^3$ of soil was added to each of the three cells. In this way, the cells are inoculated with an additional amount of electroactive microorganisms, naturally living in the soil (*Geobacter*, *Clostridium, Bacillus, Pseudomonas* and others*)* (Bratkova et al., 2018).

### Measuring of cell electrical parameters

For the polarization curve test, the anode and cathode in SPMFC were connected to a varied resistance box MCP lab electronics BXR-04 ResistorBox, and the stable voltages were recorded under varying external resistances (Wang et al., 2013). Voltages produced from the SMFCs during the experiments were recorded at 60 min intervals using a Vernier LabQuest Mini and Logger Lite software.

Power (P) was calculated according to the expression $P = IU$, where I - current and U - voltage. Current density and power density were calculated based on the electrode area (30 $cm^2$). The Ag/AgCl reference electrode was positioned near the cathode in order to measure the cathode potential. Anode redox potentials were approximated by subtracting the cell potential from cathode potentials (Song and Jiang, 2011).

## Results and discussion

The goal of this study is to integrate a microbial fuel cell with solid-phase plant organics using the composting process to generate energy. As seen in Figure 3, the voltage of all SPMFCs was low during the first 3 days of the experiment, but then increased rapidly. This may be due to the formation of an active biofilm on the surface of the electrodes (Venkata and Chandrasekhar, 2011).

SPMFCs reached their maximum voltage between day 8 and 14, remaining constant with slight fluctuations until day 65 of the experiment. The highest open circuit voltage is generated by the SPMFC with grass.

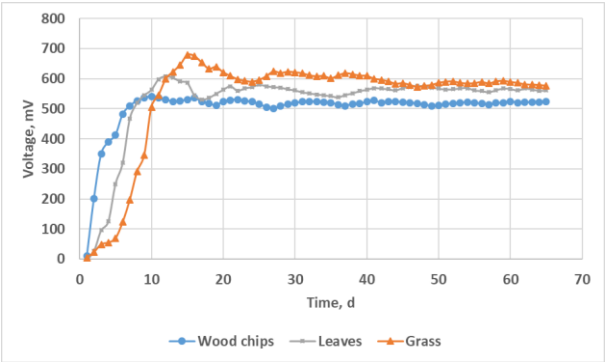



**Fig. 3. Open circuit voltage generation from SPMFCs containing green waste**

The cell reaches a maximum voltage on the 15th day (679 mV), then drops to 600 mV ± 24 and remains within these limits until the end of the experiment. The SPMFC with leaves generated a slightly lower open circuit voltage and after the 20th day, it remained around 565 mV ± 6 until the end of the experiment. The lowest open-circuit voltage is generated by the SPMFC with wood chips. After stabilisation, the voltage during the experiment was in the range of 521 mV ± 10.

Figure 4 shows the polarisation curves of the three solid phase microbial fuel cells.

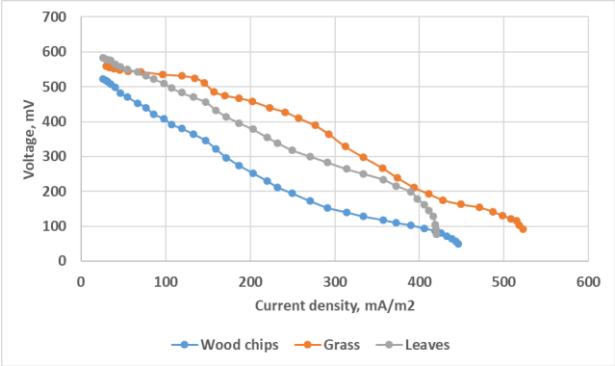



**Fig. 4. Polarisation curves of SPMFCs containing green waste**

The obtained graphs exhibit similar electrical parameters of the SPMFCs with grass and with leaves. However, the solid phase microbial fuel cell with grass shows the best results in terms of generated voltage and current density. SPMFC with wood chips is characterised by the lowest value of the measured electrical parameters.

The power density curves of the SPMFCs were obtained at day 28 and are presented in Figure 5.

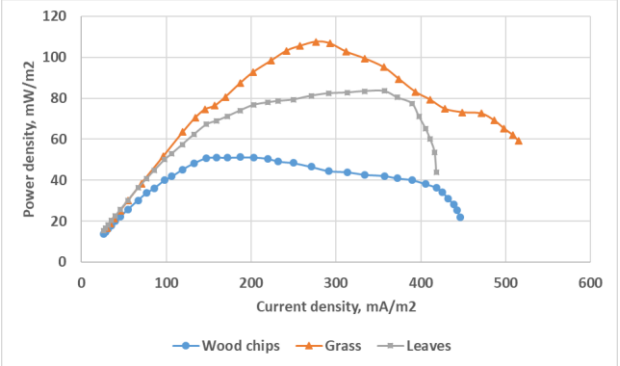



**Fig. 5. Power density (data from polarisation curves) of SPMFCs containing green waste**

The results in Figure 5 show that different organic substrates have different electrical characteristics in solid phase microbial fuel cell. This is most likely due to the different carbon / nitrogen ratio (Khudzari et al., 2016). The highest power density was achieved in the SPMFC with grass. A maximum power density of 107.58 mW/m$^2$ was obtained with this cell. A lower maximum power density was achieved for the SPMFC with leaves – 83.51 mW/m$^2$. In the SPMFC with wood chips, the lowest power density of 51.21 mW/m$^2$ was obtained.

The results for the anode and cathode potentials relative to the Ag/AgCl reference electrode are presented in Figure 6.

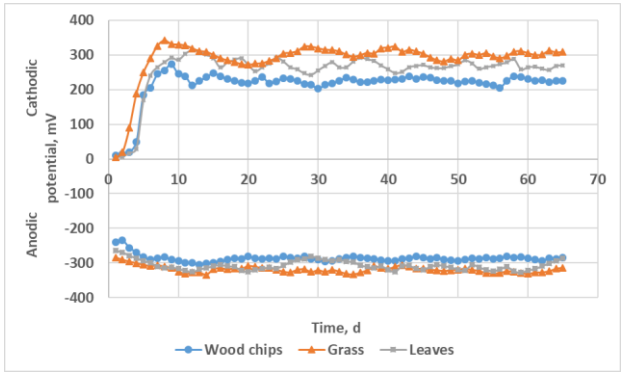



**Fig. 6. Working potential of cathodes and anodes of SMFCs containing green waste**

The cathode potentials in the SPMFCs remained relatively constant throughout the experiment after cell stabilisation. The different patterns of cathode potentials of SPMFCs may be due to the rate of biofilm formation on cathodes (Bratkova et al., 2018), which resulted in different electrochemical characteristics of cathodes in SPMFCs. The SPMFC with grass maintained the highest cathode potential throughout the experiment of 300 mV ± 20. A slightly lower cathode potential was maintained in the SPMFC with leaves. In this variant, the cathode potential after stabilisation of the cell was in the range of 270 mV ± 23. The lowest cathode potential was measured in the SPMFC with wood chips. During the experiment, it was within the range of 210 mV ± 14.

Anode potentials in all SPMFCs varied only slightly, ranging from -280 to -330 mV, whereas the cathode potentials showed significant differences. The initial anode potentials of the SPMFCs containing the green waste were negative (about -300 mV) and remained stable throughout the experiment.

## Conclusion

The present study showed the possibility of utilising the green waste from the overburden by generating energy from it in solid-phase microbial fuel cells. All three investigated organic substrates – grass, leaves and wood chips – showed that they can be a long-term source of energy. However, the SPMFC with grass showed the highest electrical performance in terms of generated voltage – 600 mV ± 24 and power density – 107.58 mW/m$^2$. The lowest values of the electrical parameters were measured for the solid-phase microbial fuel cell with wood chips – a voltage of 521 mV ± 10 and a power density of 51.21 mW/m$^2$. Between 8 and 14 days were required to reach the full potential of SPMFCs, due to processes related to biofilm formation of electroactive microorganisms on the electrodes and degradation of organic matter. After stabilising

the SPMFCs, the cells maintained a constant voltage throughout the experiment - 65 days.

The results obtained are an advance in research for the development of bioenergy sources. Further research is needed on various factors influencing the energy generated from green waste, such as the optimal carbon / nitrogen ratio, the use of cellulose-degrading enzymes, inoculation with electroactive organisms, and others. It is also necessary to conduct additional experiments related to the possibilities of storing and converting the generated energy.

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## References

Addagada, L., Goel, M., Shamid, M., Prabhu, S., Chand, S., Sahoo, N. & Rout, P. (2023). Tricks and tracks in resource recovery from wastewater using bio-electrochemical systems (BES): A systematic review on recent advancements and future directions. *Journal of Water Process Engineering*, *56*, Article 104580, https://doi.org/10.1016/j.jwpe.2023.104580

Adibi, N., Osanloo, M. & Rahmanpour, M. (2013). Adverse effects of coal mine waste dumps on the environment and their management, *Environmental Earth Science*, *70*(4)*,* 1581-1592. DOI: 10.1007/s12665-013-2243-0

Bratkova, S., Ivanov, R., Gerginova, M., Peneva, N., Angelov, A. & Alexieva, Z. (2018). Rhizosphere microflora of sediment plant microbial fuel cells. In A. Mendez-Vilas (Ed.) *Exploring microorganisms: Recent Advances in Applied Microbiology*, pp. 40-43, BrownWalker Press.

Chiu, H., Pai, T. Y., Liu, M. H., Chang, C. A., Lo, F. C., Chang, T. C., Lo, H. M., Chiang, C. F., Chao, K. P., Lo, W. Y., Lo, S. W. & Chu, Y. L. (2016). Electricity production from municipal solid waste using microbial fuel cells, *Waste Management and Research*, *34*(7), 619–629**,** https://doi.org/10.1177/0734242X16649681

Debnath, K., Dutta, S., 2023, Bio-electrochemical system analysis and improvement: A technical review, *Cleaner and Circular Bioeconomy*, *6,* Article 100052, https://doi.org/10.1016/j.clcb.2023.100052

Jambhulkar, H. & Kumar, M. (2019). Eco-restoration approach for mine spoil overburden dump through biotechnological route, *Environmental Monitoring and Assessment*, *191,* Article 772, https://doi.org/10.1007/s10661-019-7873-6

Khudzari, J. M., Tartakovsky, B. & Raghavan, G. S. V. (2016) Effect of C/N ratio and salinity on power generation in compost microbial fuel cells. *Waste Management, 48,* 135–142, https://doi.org/10.1016/j.wasman.2015.11.022

Logrono, W., Ramírez, G., Recalde, C., Echeverría, M. & Cunachi, A. (2015). Bioelectricity generation from vegetables and fruits wastes by using single chamber microbial fuel cells with high Andean soils, *Energy Procedia* *75*, 2009–2014, https://doi.org/10.1016/j.egypro.2015.07.259

Mahamaya, M., Das, S. K. (2017). Characterization of mine overburden and fly ash as a stabilized pavement material. *Particulate Science and Technology*, *35*(6), 660–666, https://doi.org/10.1080/02726351.2016.1194344

Mahmoud, R., Gomaa, O. & Hassan, R. (2022). Bio-electrochemical frameworks governing microbial fuel cell performance: technical bottlenecks and proposed solutions. *RSC Advances*, *12*, Article 5749, https://doi.org/10.1039/d1ra08487a

Mochamad, B., Syafrudin, A. E., Syarif, H., Candra, P., Ayudya, L., Fadel, M. & Bimastyaji, R. (2021). Waste valorization using solid-phase microbial fuel cells (SPMFCs): Recent trends and status. *Journal of Environmental Management*, *277,* Article 111417, https://doi.org/10.1016/j.jenvman.2020.111417

Smith, M. M. & Aber, J. D. (2018). Energy recovery from commercial-scale composting as a novel waste management strategy. *Applied Energy, 211,* 194–199, https://doi.org/10.1016/j.apenergy.2017.11.006

Song, T., Wang, D., Han, S., Wu, X. & Zhou, C. (2014). Influence of biomass addition on electricity harvesting from solid phase microbial fuel cells. *International Journal of Hydrogen Energy*, *39*(2), 1056-1062, https://doi.org/10.1016/j.ijhydene.2013.10.125

Spargo, A. & Doley, D. (2016). Selective coal mine overburden treatment with topsoil and compost to optimise pasture or native vegetation establishment. *Journal of Environmental Management*, *182,* 342-350, https://doi.org/10.1016/j.jenvman.2016.07.095

Song, T. S. & Jiang, H. L. (2011). Effects of sediment pretreatment on the performance of sediment microbial fuel cells, *Bioresource Technology*, *102*, 10465-10470, https://doi.org/10.1016/j.biortech.2011.08.129

Utomo, H. D., Yu, L. S., Zhi Yi, D. C. & Jun, O. J. (2017). Recycling solid waste and bioenergy generation in MFC dual-chamber model. *Energy Procedia*, *143*, 424–429, https://doi.org/10.1016/j.egypro.2017.12.706

Venkata, S. & Chandrasekhar, K. (2011). Solid phase microbial fuel cell (SMFC) for harnessing bioelectricity from composite food waste fermentation: Influence of electrode assembly and buffering capacity. *Bioresource Technology*, *102* (14), 7077-7085 https://doi.org/10.1016/j.biortech.2011.04.039

Wang, C. T., Lee, Y. C. & Liao, F. Y. (2015). Effect of composting parameters on the power performance of solid microbial fuel cells. *Sustainability 7*(9), 12634–12643, https://doi.org/10.3390/su70912634

Wang, C. T., Liao, F. Y. & Liu, K. S. (2013). Electrical analysis of compost solid phase microbial fuel cell, *International Journal of Hydrogen Energy 38*(25), 11124–11130 https://doi.org/10.1016/j.ijhydene.2013.02.120

Wang, S., Hadji-Thomas, A., Adekunle, A. & Raghavan, V., (2024). The exploitation of bio-electrochemical system and microplastics removal: Possibilities and perspectives, *Science of Total Environment*, *930,* Article 172737, https://doi.org/10.1016/j.scitotenv.2024.172737