Microbial Fuel Cells' Integration in Constructed Wetlands: A Mini-Review

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Background & Aims: Constructed wetlands (CW) are widely recognized as an effective nature-based solution for wastewater treatment with benefits that include low energy consumption, ecological enhancement, aesthetics, and carbon sequestration potential (Calheiros et al., 2015; Vymazal, 2011). As stated by Justino et al. (2023) and Vymazal (2011) CW's performance could be enhanced through hybrid configurations, combining different hydraulic flows (vertical or horizontal), macrophyte types (emergent, submerged, or floating), and hydrological regimes (subsurface or surface flow). In addition to their treatment capacity, CW are characterized by having organic matter in their substrate and surrounding wastewater, and hosting microbial communities capable of electricity generation through biocatalytic metabolism, under anaerobic conditions. This dual functionality of a CW has been demonstrated in several studies (Angassa et al., 2024; Jacobs et al., 2024). The electroactive bacteria oxidize organic matter and transfer electrons to the anode. The electrons are then transferred to the cathode region through an external resistance. This process results in the generation of bioelectricity while simultaneously treating wastewater. This is the basic principle of microbial fuel cells (MFC) operation. This study aims to critically review current research on the integration of MFCs into CW, focusing on electricity generated from the organic matter content present in the wastewater. **Methods:** The study proposes a systematic review of relevant scientific literature, with a particular focus on recent developments in MFC associated to CW (Colares et al., 2022). Emphasis will be placed on decentralized wastewater treatment scenarios where influent

quality and quantity fluctuate, as typically observed in rural tourism facilities. Implementation challenges such as system complexity, potential toxicity from electrode materials, and pollutants accumulation will also be assessed. The review will be carried out based on scientific databases such as ScienceDirect, SpringerLink, and Scopus to identify trends, technological frameworks, and knowledge gaps. **Results:** The review provides insights into the current state of MFC application in CW, comparing their performance in treating wastewater and assessing their energy recovery potential. **Conclusion:** The findings will support the development of a conceptual framework for integrating MFC into CW, enabling more sustainable, decentralized water treatment systems. This contributes directly to SDG 6 by enhancing access to safe water, SDG 11 through support for resilient and sustainable community infrastructure, and SDG 13 by promoting low-carbon, energy-generating wastewater technologies that mitigate climate impact.

Keywords:

Constructed Wetland, Advanced Technologies, Microbial Fuel Cells, Bioelectricity Generation, Microbial Metabolism, nature-based solutions

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References:

Angassa, K., Getu, T., & Abewaa, M. (2024). Removal of nutrients and bioelectricity generation from institutional wastewater using constructed wetland-microbial fuel cell. *Results in Engineering*, *24*, 103254. https://doi.org/https://doi.org/10.1016/j.rineng.2024.103254

Calheiros, C. S. C., Bessa, V. S., Mesquita, R. B. R., Brix, H., Rangel, A. O. S. S., & Castro, P. M. L. (2015). Constructed wetland with a polyculture of ornamental plants for wastewater treatment at a rural tourism facility. *Ecological Engineering*, *79*, 1–7. https://doi.org/https://doi.org/10.1016/j.ecoleng.2015.03.001

Colares, G. S., Dell'Osbel, N., Paranhos, G., Cerentini, P., Oliveira, G. A., Silveira, E., Rodrigues, L. R., Soares, J., Lutterbeck, C. A., Rodriguez, A. L., Vymazal, J., & Machado, Ê. L. (2022). Hybrid constructed wetlands integrated with microbial fuel cells and reactive bed filter for wastewater treatment and bioelectricity generation. *Environmental Science and Pollution Research*, *29*(15), 22223–22236. https://doi.org/10.1007/s11356-021-17395-5

Jacobs, D. G., Kachienga, L. O., Rikhotso, M. C., Abia, A. L. K., Traoré, A. N., & Potgieter, N. (2024). Assessing the current situation of constructed wetland-microbial fuel cells as an alternative power generation and wastewater treatment in developing countries. *Frontiers in Energy Research*, *Volume 12-2024*. https://doi.org/10.3389/fenrg.2024.1448730

Justino, S., Calheiros, C. S. C., Castro, P. M. L., & Gonçalves, D. (2023). Constructed Wetlands as Nature-Based Solutions for Wastewater Treatment in the Hospitality Industry: A Review. *Hydrology*, *10*(7). https://doi.org/10.3390/hydrology10070153

Vymazal, J. (2011). Constructed Wetlands for Wastewater Treatment: Five Decades of Experience. *Environmental Science & Technology*, *45*(1), 61–69. https://doi.org/10.1021/es101403q