Received: 30 October 2019 | Revised: 6 April 2020 | Accepted: 12 April 2020

DOI: 10.1111/1440-1703.12134

SPECIAL FEATURE

ECOLOGICAL RESEARCH WILEY

Promoting idea sharing via Idea Paper

Idea paper: Community-interaction analyses contribute to improving the performance of microbial fuel cells

Hideyuki Doi

Graduate School of Simulation Studies, University of Hyogo, Kobe, Japan

Correspondence
Hideyuki Doi, Graduate School of Simulation Studies, University of Hyogo, 7-1-28 Minatojima-minamimachi, Chuo-ku, Kobe 650-0047, Japan.
Email: hideyuki.doi@icloud.com

Abstract

Renewable energy resources can potentially solve global warming issues that arise from the large amounts of CO_2 emissions from currently used energy resources. Microbial fuel cells (MFC) can produce electrical energy from the environment, making them attractive for energy harvesting. The structures and mechanisms of MFC have been studied for a few decades, and the performance of MFC has constantly been improved using new materials in the devices or by interacting microbial species on the anode chamber of MFC. However, the ecological phenomena, especially inter-species interactions, within the microbial community in MFC are still largely unknown. Analysis and control of the microbial community have high potential to improve the MFC performance. In this idea paper, I have provided ways to analyze the species interactions in the microbial communities of MFC: (a) empirical dynamic modeling for detecting species interactions in MFC, and (b) network analysis to explore the core microbe species in the MFC. The interaction analyses of the microbial communities in MFC devices can potentially contribute to improving the performance of MFC.

KEYWORDS

community, ecosystem function, empirical dynamic modeling, microbial fuel cells, network analysis

1 | RESEARCH QUESTION

Interest in microbial fuel cell (MFC) technology has been increasing because of its capacity to produce electrical energy from the environment (Franks & Nevin, 2010; Kumar, Singh, Zularisam, & Hai, 2018), thus, recognizing it as an important energy harvesting technique (Wang, Park, & Ren, 2015). MFC concepts can especially be applied to the energy sources used in environmental sensors, as well as for sewage treatment (Kumar et al., 2018; Watanabe, 2008). Recently, MFC structures have been increasingly studied, and MFC performance, including its ability to produce electronic voltage, has been largely improved (Franks & Nevin, 2010; Kumar et al., 2018).

MFC are bio-electrochemical devices that typically have two chambers, namely the anode (anaerobic; contains an electrode, microorganisms, and an anolyte) and the cathode (aerobic/anaerobic; an electrode, an electron acceptor, and a catalyst) (Figure 1). Microbes in the anode chamber of MFC are used as biocatalysts to oxidize substrates; because of this, they have been termed as the powerhouse of MFC. The electrons are transferred to the anodic surface, which are then directed to the cathode through an electrical connection. In the cathode, electrons combine with protons and oxygen to form water. MFC performance mainly depends on the efficiency of microorganisms to act as biocatalysts in the MFC chambers and inter-species interaction for biocatalysts and

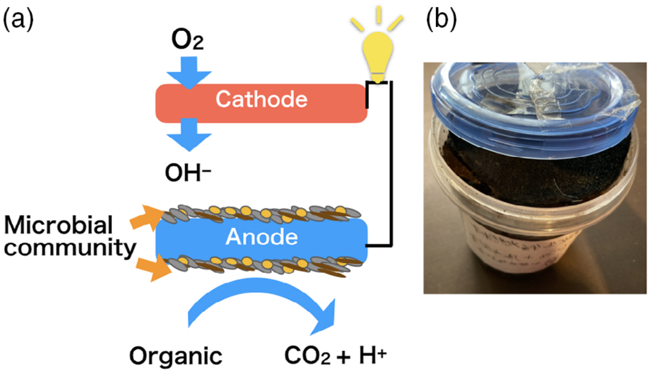

FIGURE 1 Typical microbial fuel cell (MFC) structure. (a) The illustration of a typical MFC mechanism. (b) The MFC device made by Tamon Doi. The plastic bottle was filled by soil from house garden. The cathode on the soil (see the surface of the soil) was made by carbon felt and the anode (carbon felt) in the soil connected with a bronze line to the cathode [Color figure can be viewed at wileyonlinelibrary.com]

energy transfer to anode (Hindatu, Annuar, & Gumel, 2017; Park et al., 2014). Although MFC performance has been improved by newly discovered materials for devices or by interacting microbial species on the anode chamber, the studies regarding microbial interactions in MFC are still limited (Li et al., 2016; Shimoyama, Yamazawa, Ueno, & Watanabe, 2009). The application of the inter-specific interaction analysis used in community ecology may overcome this limitation.

2 | VALUE

Extracting energy from MFC can solve energy and environmental issues simultaneously (Franks & Nevin, 2010; Kumar et al., 2018). Building and controlling an ideal microbial community in MFC has high potential to improve the electronic power, power density, and longevity. MFC could increase the capability to use a device for energy harvesting.

3 | RELEVANT HYPOTHESIS

Previous studies have found that electrode materials, such as materials used in the anode and cathode, as well as the microorganisms and organic resources added to the MFC, can impact microbial colonization, which consequently improves MFC performance (Pinto, Coradin, & Laberty-Robert, 2018). Many studies have improved MFC performance, including the development of a harness, electrode, and proton exchange membrane (Harnisch, Schröder, & Scholz, 2008); however, at present, there are only a few ecological approaches that are being used; for example, Park et al. (2014) suggested the inter-species interactions between exoelectrogens and hydrogenotrophic microbes to increase MFC performance throughout exchanging hydrogen productions in microbial species network. Although species interaction, for example, energy transfer among microbes, increase MFC performance, inter-species interactions in microbes in MFC are largely unknown.

4 | NEW RESEARCH IDEA

My idea is to apply community interaction analyses to improve MFC performance. Specifically, community analyses of microbial communities in MFC would be useful to reveal interactions and community structures under differing MFC resource availabilities and MFC device conditions.

5 | HOW TO SOLVE THE QUESTION THROUGH THE NEW IDEA

For community interaction analysis, two approaches are available, namely (a) empirical dynamic modeling (EDM) approach for detecting causal species interactions using time-series data and (b) network analysis for species interaction using snapshot data of the community. Recently developed DNA metabarcoding techniques enable obtaining data for the community interaction analyses (Young, Austin, & Weyrich, 2017). In this idea paper, I assumed the data for the both analyses obtained by 16S amplicon sequencing by high-throughput sequencing.

5.1 | EDM approach

EDM is a nonlinear time-series analysis for complex systems (Sugihara et al., 2012). In EDM, convergent cross mapping and the multivariate S-map enables detecting causal relationships of microbes and quantifications of time-varying interspecific interactions in a community (Deyle, May, Munch, & Sugihara, 2016; Sugihara et al., 2012; Ushio et al., 2018). However, EDM requires a time-series data that includes around 30–40 data points, as such, we should have a similar time-series data for microbial communities in MFC. From the EDM analysis, we can obtain the strength/direction of species interactions over time and the information can be useful to consider the dynamics of microbial interaction along with changing the resources (e.g., organic sources) and the MFC performance (e.g., the flow of hydrogen and electrons). EDM requires absolute abundance data of community. I thus recommend quantifying the community abundance using quantitative DNA metabarcoding approaches (Hoshino & Inagaki, 2017; Ushio, 2019).

5.2 | Network analysis

Network analysis has been used to reveal the complex interactions among microbial species (Toju et al., 2018; Yang, Yu, Cheng, & Ning, 2019). Species–species network analysis would be useful in exploring "core" and "hub" species in a microbial network and their contributions for MFC performance. When we found the core and hub microbes, we were able to link the characterized network and the MFC performance to explore the ideal network for MFC improvement.

In previous studies, researchers have tried to identify the community structures in MFC (Li et al., 2016; Shimoyama et al., 2009). However, the previous studies did not use EDM and network approaches for species interactions in MFC. The results from the above-provided approaches would improve the performance of MFC throughout creating the microbe community considering with species interactions strength and direction among the microbes, and introducing "core" microbes. Further studies on the microbial communities in MFC can, thus, increase the possibility of using MFC as future energy resources.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

ORCID

Hideyuki Doi https://orcid.org/0000-0002-2701-3982

REFERENCES

Deyle, E. R., May, R. M., Munch, S. B., & Sugihara, G. (2016). Tracking and forecasting ecosystem interactions in real time. *Proceedings of the Royal Society B: Biological Sciences*, *283*, 20152258.

Franks, A. E., & Nevin, K. P. (2010). Microbial fuel cells, a current review. *Energies*, *3*, 899–919.

Harnisch, F., Schröder, U., & Scholz, F. (2008). The suitability of monopolar and bipolar ion exchange membranes as separators for biological fuel cells. *Environmental Science & Technology*, *42*, 1740–1746.

Hindatu, Y., Annuar, M. S. M., & Gumel, A. M. (2017). Mini-review: Anode modification for improved performance of microbial fuel cell. *Renewable and Sustainable Energy Reviews*, *73*, 236–248.

Hoshino, T., & Inagaki, F. (2017). Application of stochastic labeling with random-sequence barcodes for simultaneous quantification and sequencing of environmental 16S rRNA genes. *PLoS One*, *12*, e0169431.

Kumar, R., Singh, L., Zularisam, A. W., & Hai, F. I. (2018). Microbial fuel cell is emerging as a versatile technology: A review on its possible applications, challenges and strategies to improve the performances. *International Journal of Energy Research*, *42*, 369–394.

Li, X., Wang, X., Wan, L., Zhang, Y., Li, N., Li, D., & Zhou, Q. (2016). Enhanced biodegradation of aged petroleum hydrocarbons in soils by glucose addition in microbial fuel cells. *Journal of Chemical Technology & Biotechnology*, *91*, 267–275.

Park, T. J., Ding, W., Cheng, S., Brar, M. S., Ma, A. P. Y., Tun, H. M., & Leung, F. C. (2014). Microbial community in microbial fuel cell (MFC) medium and effluent enriched with purple photosynthetic bacterium (*Rhodopseudomonas* sp.). *AMB Express*, *4*, 1–8.

Pinto, D., Coradin, T., & Laberty-Robert, C. (2018). Effect of anode polarization on biofilm formation and electron transfer in *Shewanella oneidensis/graphite* felt microbial fuel cells. *Bioelectrochemistry*, *120*, 1–9.

Shimoyama, T., Yamazawa, A., Ueno, Y., & Watanabe, K. (2009). Phylogenetic analyses of bacterial communities developed in a cassette-electrode microbial fuel cell. *Microbes and Environments*, *24*, 188–192.

Sugihara, G., May, R., Ye, H., Hsieh, C. H., Deyle, E., Fogarty, M., & Munch, S. (2012). Detecting causality in complex ecosystems. *Science*, *338*, 496–500.

Toju, H., Peay, K. G., Yamamichi, M., Narisawa, K., Hiruma, K., Naito, K., … Yoshida, K. (2018). Core microbiomes for sustainable agroecosystems. *Nature Plants*, *4*, 247–257.

Ushio, M. (2019). Use of a filter cartridge combined with intra-cartridge bead-beating improves detection of microbial DNA from water samples. *Methods in Ecology and Evolution*, *10*, 1142–1156.

Ushio, M., Hsieh, C. H., Masuda, R., Deyle, R. E., Ye, H., Chang, C. W., … Kondoh, M. (2018). Fluctuating interaction network and time-varying stability of a natural fish community. *Nature*, *554*, 360–363.

Wang, H., Park, J. D., & Ren, Z. J. (2015). Practical energy harvesting for microbial fuel cells: A review. *Environmental Science & Technology*, *49*, 3267–3277.

Watanabe, K. (2008). Recent developments in microbial fuel cell technologies for sustainable bioenergy. *Journal of Bioscience and Bioengineering*, *106*, 528–536.

Yang, P., Yu, S., Cheng, L., & Ning, K. (2019). Meta-network: Optimized species-species network analysis for microbial communities. *BMC Genomics*, *20*, 187.

Young, J. M., Austin, J. J., & Weyrich, L. S. (2017). Soil DNA metabarcoding and high-throughput sequencing as a forensic tool: Considerations, potential limitations and recommendations. *FEMS Microbiology Ecology*, *93*, fiw207.

How to cite this article: Doi H. Idea paper: Community-interaction analyses contribute to improving the performance of microbial fuel cells. *Ecological Research*. 2020;35:583–585. https://doi.org/10.1111/1440-1703.12134