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Review

A genetic approach for microbial electrosynthesis system as biocommodities production platform

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HIGHLIGHTS

- Microbial electrosynthesis is promising technology as biocommodities production.
- Extracellular electron transfer is key point of microbial electrosynthesis.
- Genetic engineering can solve the problems of microbial electrosynthesis.
- This article proposes recommended host cells.

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ABSTRACT

Microbial electrosynthesis is a process that can produce biocommodities from the reduction of substrates with microbial catalysts and an external electron supply. This process is expected to become a new application of a cell factory for novel chemical production, wastewater treatment, and carbon capture and utilization. However, microbial electrosynthesis is still subject to several problems that need to be overcome for commercialization, so continuous development such as metabolic engineering is essential. The development of microbial electrosynthesis can open up new opportunities for sustainable biocommodities production platforms. This review provides significant information on the current state of MES development, focusing on extracellularly electron transfer and metabolic engineering.

Contents

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1. Introduction

Bioelectrochemical systems (BESs) use microorganisms as a bioelectrocatalyst in electrochemical reactions. BESs have both biological advantages such as self-replication, and electrochemical advantages such as a mass-free supply of redox equivalents and the use of the cheapest redox equivalent-the electron (Krieg et al., 2014; Wandrey, 2004). Starting with microbial fuel cell (MFC), which produces electricity by anodic microbial oxidation, various BES technologies such as microbial electrosynthesis (MES), microbial desalination cell (MDC) or biocomputing system have been introduced. In particular, MES is promising technology as a cell factory for biocommodities production because this can produce organic matters with microbial electrocatalysts (Schröder et al., 2015).

One of the main focus of MES research is to discover which and how specific microorganisms can accept external electrons supplied from an electrode to reduce the terminal electron acceptor. In the early stages, MES studies utilized mediators such as neutral red to promote the reactivity of microbial metal oxidation with Fe (II) or to increase product yields of glutamic acid in glucose fermentation (Hongo and Iwahara, 1979; Kinsel and Umbreit, 1964). These mediator-driven MES reactions with neutral red were also carried out under mixed-cultured methanogenesis, as well as pure-cultured *Escherichia coli*, *Klebsiella pneumoniae*, and *Zymomonas mobilis* (Harrington et al., 2015a; Park et al., 1999). However, since it was found that *Geobacter* sp. could reduce fumarate to succinate by forming a biofilm on a cathode, microbial direct electron transfer without external mediators has been intensively explored (Gregory et al., 2004). Acetogenic bacteria including *Sporomusa* spp. and *Clostridium* spp., and autotrophic Fe(II) oxidizing bacteria (e.g., *Acidithiobacillus ferroxidans*) were identified as the microorganism capable of directly accepting electrons from an electrode (Ishii et al., 2015; Nevin et al., 2011).

In the cases of where carbon dioxide (CO_2) is used for an electron acceptor, MES can play a large role in carbon capture and utilization (CCU) technology beyond biocommodities production, which has become more important after the Paris Agreement. CO_2 is converted into "electrofuel" in a similar way to photosynthesis by the interaction of electricity and microbial (Choi and Sang, 2016).

$$nCO_2 + (6n+2)(e^{-1} + H^+) \rightarrow C_nH_{2n+2} + 2nH_2O$$

This electrofuel is efficient delivering electricity to products (80–90%) which means it is more efficient sunlight to biomass of photosynthesis in many crops (below 3%), as well as more scalable and feedstock-flexible (Conrado et al., 2013; Tremblay and Zhang, 2015). Also, the system is land-independent, so MES is expected to be able to serve for CCU (Lovley, 2011).

However, MES still has some challenges; CO_2 reduction in MES is relatively slow and the growth of the cathodic microbial communities tends to be slower than that of anodic microbial communities (Rozendal et al., 2008; Tremblay and Zhang, 2015). Also, it is not certain how microorganisms accept electrons and how they use these electrons to synthesize. To solve these problems, many researchers have approached MES electrochemically, economically, and biologically. In particular, genetic engineering can be considered as a means of MES improvement because it can modify microorganisms to track a desired pathway and control expression, via loss or gain of function. Despite this importance, few reviews that clearly summarized genetic engineering approaches in MES have been published, compared to operational, technological, and/or pathway-identification approaches. Thus, this article provides information on not only two parameters and electron transfer pathways, but also genetic engineering approaches of MES.

2. The effect of electrode and potential on MES

Although metabolic aspects of microorganisms are an important factor in MES, non-microbial factors also affect effectiveness of MES. Therefore, in order to increase process effectiveness and

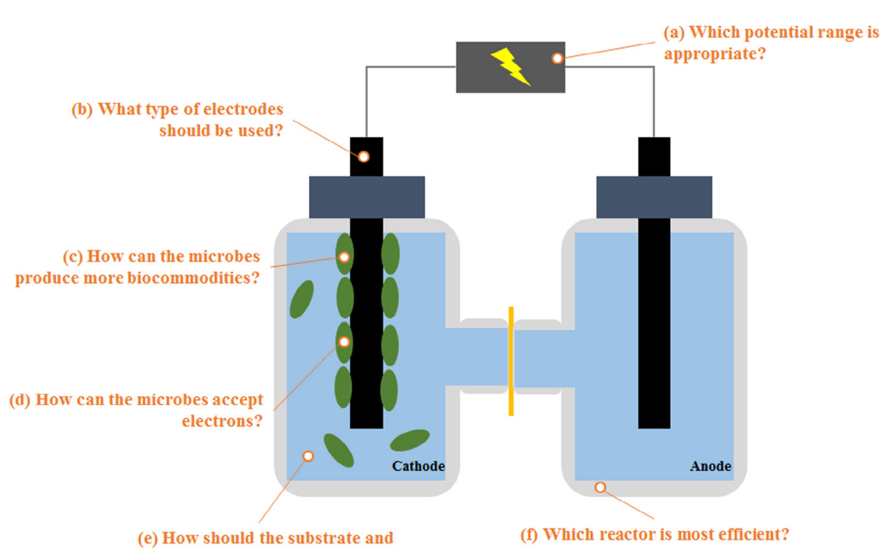

Fig. 1. Points capable of improvement various parts of MES.

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