

# ROUTES: Innovative system solutions for municipal sludge treatment and management

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Exploiting Microbial electrolysis cells (MEC) to reduce both sludge production and energy requirements in wastewater treatment plants (Task 2.3)

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Both Microbial fuel cells (MFCs) and Microbial electrolysis cells (MEC) aim to simultaneous wastewater treatment and energy recovery, through electricity generation or biofuel production, respectively.

In a MFC (Figure 1A), bacteria use an anode as electron acceptor for the oxidation of organic carbon in the wastewater to CO<sub>2</sub>, with production of protons and electrons. The protons are transferred to a cathode through an ion-exchange membrane while the electrons are transferred via an electrical circuit, where a load harvests the energy liberated by the reaction. At the cathode an electron acceptor (usually oxygen) is chemically reduced using the electrons delivered by the anode (Logan et al. 2006). In this way, MFCs have been shown to convert organic acids (Aelterman et al. 2008;), carbohydrates (Chaudhuri and Lovley 2003; Rabaey et al. 2003), and real wastewater (Aelterman et al. 2006; Min et al. 2005; Min and Logan 2004) into electric energy. However, MFC power outputs are low (10-100 W/m<sup>3</sup>) and not yet competitive with energy production from methane fermentation.

As an alternative, microbial electrolysis cells (MEC) (Figure 1B), a variant of conventional MFC, have been proposed for the production of hydrogen or methane gas. In a H<sub>2</sub>-producing MEC, the cathode has to be kept anaerobic; thus the electrons released from the oxidation of organic matter, reduce the protons to H<sub>2</sub>, in the presence of a suitable catalyst such as Pt or Pd (Logan et al. 2008). Biological cathodes have been recently proposed as a suitable alternative to overcome the need of using noble metals and to further reduce the overpotential at the cathodic surface (Aulenta et al. 2008; Aulenta et al. 2012; Rozendal et al. 2008; Villano et al. 2011a). Since in MEC the electron-releasing reactions (oxidation of organic waste materials) are physically separated by the electron-consuming H<sub>2</sub>-producing reaction, MEC can overcome two major bottlenecks of the (dark) fermentative H<sub>2</sub> production i.e. the need of using only carbohydrate-rich substrates as feedstock and the low H<sub>2</sub> yields due to the accumulation of side products which are not further converted into H<sub>2</sub> (acetate, butyrate ...).

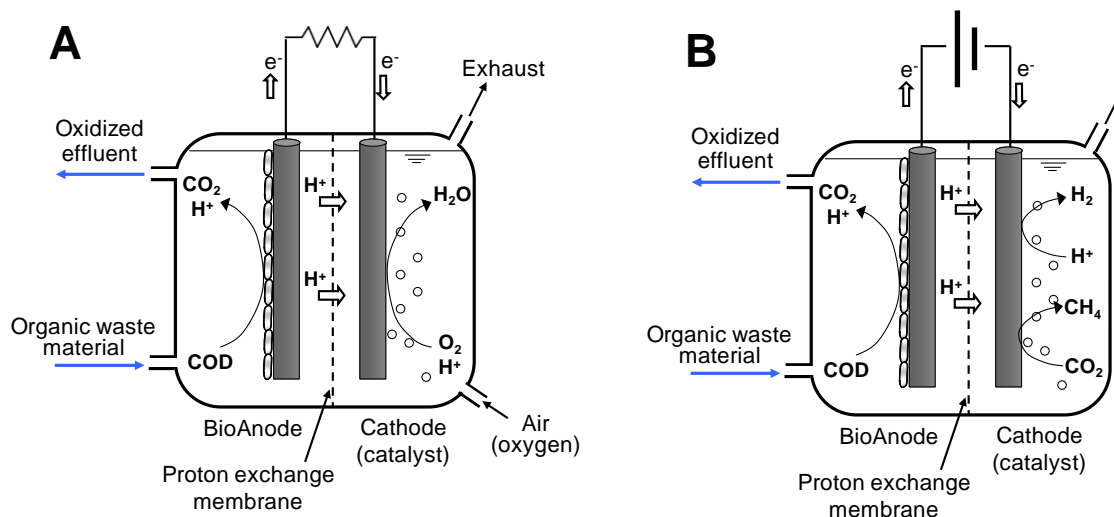


Figure 1. Schematics of a microbial fuel cell (MFC) (A) and a microbial electrolysis cell (MEC) (B)

In a CH<sub>4</sub>-producing MEC, the electrons released from the anodic oxidation of organic matter are used for CO<sub>2</sub> reduction into methane, by using a suitable chemical or biological catalyst. The latter include methanogenic consortia, similar to anaerobic digestion (AD) (Cheng et al. 2009; Villano et al. 2010; Villano et al. 2011b). Of course, AD is an outstanding competitor because it is a well-established biotechnology, able to convert waste organic substrates into biogas (the mixture primarily consisting of methane and carbon dioxide) in a single reactor, at high load and with high yield. However, the AD technology is still facing with the susceptibility of methanogenic microorganisms to toxic compounds, the need to operate the bioprocess at temperatures at or above 35 °C (which restricts its applicability to high-strength wastewater only), the inefficient nutrient removal, and the difficulty in removing the organic substrates down to low residual concentrations. For the latter reason, in order to meet stringent effluent discharge limits, AD systems require a “polishing” post-treatment step, that is typically achieved in energy-intensive activated sludge systems, where the residual organic matter is aerobically oxidized to carbon dioxide and water, with concomitant production of considerable amounts of sludge. This opens a competitive niche for MECs that appear more suitable for achieving lower discharge limits than AD as well as for treating low-strength wastewater. The latter is also due to that in MEC methanogenic reaction occurs in a separate chamber with no influent liquid flow, thereby decreasing the energy requirement for temperature control and also protect methanogens from toxic compounds or competitive reactions.

Differently from MFCs, H<sub>2</sub> or CH<sub>4</sub> MECs typically require the voltage generated from substrate oxidation (at the anode) to be externally boosted/augmented in order to drive the production of the reduced end-product (H<sub>2</sub> or CH<sub>4</sub>) at the cathode, otherwise energetically unfeasible. Minimization of this electrical energy demand requires sustainable and economically viable cathode catalysts. As above reported, bio-catalyzed cathodes in which self-sustaining microorganisms can replace noble metal catalysts are extremely promising (Rosenbaum et al. 2011).

Based on the present state of art, MECs are presently being investigated in ROUTES FP7 collaborative project, in the mainframe of minimization and optimal management of sludge production in municipal wastewater treatment plants. The specific aim will be twofold:

- 1) Using MEC as novel bioreactors for treatment of low-strength wastewater (< 1 kgCOD/m<sup>3</sup>, i.e. unsuitable for anaerobic digestion) while also minimizing biomass growth yield and consequent sludge production. To achieve this target, in principle MECs have the advantage that the anode potential can be poised as low as possible, so minimizing the energy available from anaerobic oxidation that is diverted to the biomass growth. At the same time, this reflects into more reducing equivalents available for cathodic reactions, i.e for H<sub>2</sub> or CH<sub>4</sub> production, so maximizing energy recovery from the system. Of course, both the carbon and energy balances will strictly depend on internal resistances that control both mass and charge transfer through and across the MEC compartments, that in turn will depend on MEC assembly (i.e. geometry, electrodic materials, membrane) and on operating conditions (applied anodic or cathodic potential, organic and hydraulic load, wastewater composition). In this perspective, MEC development and exploitation do not require that MEC will outcompete AD in terms of net energy recovery (that seems a really difficult target) but only that net energy requirement and sludge production will be less than traditional technologies for treatment of low-strength wastewater (e.g. activated sludge process and municipal wastewater).
- 2) Above reported features also suggest that CH<sub>4</sub>-producing MEC could be used to refine both the liquid and gaseous effluents of a conventional AD system (Villano et al. 2012). This approach is particularly attractive because AD effluents primarily consist of diluted organic acids which are ideal substrates for electroactive bacteria and so can be further removed to avoid recirculation of AD effluent into the wastewater treatment plant. At the same time, continuously bubbling the biogas produced from AD through the MEC cathode will supply CO<sub>2</sub> for methane formation, that could be a strategy to refine biogas by increasing its methane content and so its energetic and economic value. Hence, coupling AD and MEC in the sludge line of wastewater treatment plant will also contribute to decrease net sludge production while increasing the energy recovery

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