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Bioelectrochemical biogas upgrade: A novel technology for reduction of carbon dioxide (CO_2) into methane

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Residual biomass, comprise a renewable energy source, that can be recovered into biogas through anaerobic digestion. Biogas upgrade into biomethane attracts scientific attention since biomethane (more than 95% methane content) can be used as a vehicle fuel and a natural gas substitute. Biogas upgrade is currently conducted by separating CO_2 from biogas using energy-consuming physicochemical processes (Muñoz et al., 2015). On the other hand, in biological biogas upgrade, CO_2 is converted into CH_4, using an external H_2 source (Götz et al., 2016). The concept of the conversion of the CO_2 is further applied in the bio-electrochemical biogas upgrade, a promising and innovative method, in which no H_2 supply is required.

Therefore, the goal of the present study, is the development of a novel technology for biogas upgrade, by the coupling of biological and electrochemical processes, using the concept of microbial electrochemistry. The research is focused on the the reduction of CO_2 into CH_4 by a methanogenic mixed culture, in the bio-cathode of a Microbial Electrochemical Cell (MEC), by artificially supplying electrons, using electric current as energy source (Xu et al., 2014). The **bio-electrochemical biogas upgrade**, can be done through (Villano et al., 2010): i) "**hydrogenotrophic methanogenesis**", in which the microorganisms convert CO_2 to CH_4 in the bulk of the MEC, using the electrochemically or bio-electrochemically produced H_2 as electron donor and (ii) "**electro-methanogenesis**", in which the methanogenic culture receives electrons directly from the bio-cathode (electrode) to reduce CO_2 to CH_4.

A multi-methodology study is carried out in an effort to extract the optimum operating conditions, in order to maximize biomethane production with low use of electrical energy. Special designed *H*-type MECs, consisting of a cathodic and an anodic cell (separated by a proton exchange membrane), have been used (Figure 1). The cathodic cell of the MECs, is inoculated using mixed culture of hydrogenotrophic methanogenic microorganisms, enriched from a biogas upgrade bench-scale bio-reactor, under anaerobic conditions and appropriate growth media (Kougias et al., 2013). The *H*-MEC cathode is fed with CO_2, in order to evaluate the CO_2 conversion rate, the CH_4 production, and the microbial growth. Different types of cathodic and anodic electrodes (graphite rods, carbon paper, Pt/Ti, IrO_2-RuO_2/Ti, etc.), have been selected to be studied, in terms of biocompatibility, current consumption, and biomethane formation. Silver-silver chloride (Ag/AgCl) electrode, is used as reference electrode. In order to promote electrons' transfer in the *H*-MECs, factors such as electrodes' surface area, electric power, redox potential, solution conductivity, etc., will be optimized. The **electroactivity** of the mixed culture in the *H*-MECs is assessed by applying **cyclic voltammetry**, via the connection of the cathodic and anodic electrodes with a potentiostat (NEV4, Alcala de Henares, Spain).

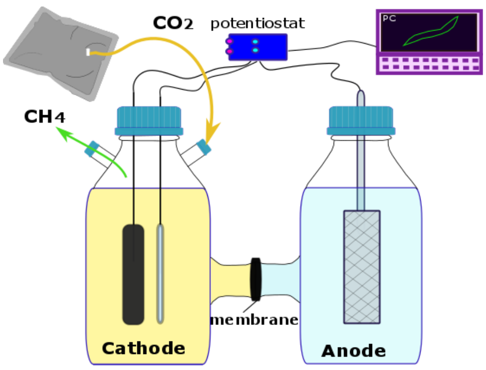

Figure 1. *H-MEC system used in the present work.*

It should be noted, that the present study, focuses on the ***ex-situ*** **biogas upgrade** (biogas production and upgrade at different reactors), since the simultaneous production and biogas upgrade in the same MEC, could lead to operating problems. The final goal of the study, is the development of a novel environmental-friendly and smart energy technology, for maximum biomethane production, from biogas produced by residual biomass (manure, biomass silage), under realistic conditions.

This study, has the perspective to shed light on issues regarding a novel promising technology for low-cost production of economically exploitable biomethane, with environmental and industrial interest. The wise use of electric energy to upgrade biogas into biomethane is undoubtedly an attractive and novel challenge, yielding substantial ecological and economic benefits, including aspects such as environmental protection and bioenergy production.

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