Thermo-Economic Evaluation of Sustainable Biogas Upgrading via Solid-Oxide Electrolysis

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Abstract : Biogas production from anaerobic digestion of organic sludge from wastewater treatment as well as various urban and agricultural organic wastes is of great significance to achieve a sustainable society. Two upgrading approaches for cleaned biogas can be considered: (1) direct H_2 injection for catalytic CO_2 methanation and (2) CO_2 separation from biogas. The first approach usually employs electrolysis technologies to generate hydrogen and increases the biogas production rate; while the second one usually applies commercially-available highly-selective membrane technologies to efficiently extract CO_2 from the biogas with the latter being then sent afterward for compression and storage for further use. A straightforward way of utilizing the captured CO_2 is on-site catalytic CO_2 methanation. From the perspective of system complexity, the second approach may be questioned, since it introduces an additional expensive membrane component for producing the same amount of methane. However, given the circumstance that the sustainability of the produced biogas should be retained after biogas upgrading, renewable electricity should be supplied to drive the electrolyzer. Therefore, considering the intermittent nature and seasonal variation of renewable electricity supply, the second approach offers high operational flexibility. This indicates that these two approaches should be compared based on the availability and scale of the local renewable power supply and not only the technical systems themselves. Solid-oxide electrolysis generally offers high overall system efficiency, and more importantly, it can achieve simultaneous electrolysis of CO_2 and H_2O (namely, co-electrolysis), which may bring significant benefits for the case of CO_2 separation from the produced biogas. When taking co-electrolysis into account, two additional upgrading approaches can be proposed: (1) direct steam injection into the biogas with the mixture going through the SOE, and (2) CO_2 separation from biogas which can be used later for co-electrolysis. The case study of integrating SOE to a wastewater treatment plant is investigated with wind power as the renewable power. The dynamic production of biogas is provided on an hourly basis with the corresponding oxygen and heating requirements. All four approaches mentioned above are investigated and compared thermo-economically: (a) steam-electrolysis with grid power, as the base case for steam electrolysis, (b) CO_2 separation and co-electrolysis with grid power, as the base case for co-electrolysis, (c) steam-electrolysis and CO_2 separation (and storage) with wind power, and (d) co-electrolysis and CO_2 separation (and storage) with wind power. The influence of the scale of wind power supply is investigated by a sensitivity analysis. The results derived provide general understanding on the economic competitiveness of SOE for sustainable biogas upgrading, thus assisting the decision making for biogas production sites. The research leading to the presented work is funded by European Union's Horizon 2020 under grant agreements n° 699892 (ECo, topic H2020-JTI-FCH-2015-1) and SCCER BIOSWEET.
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