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Research review paper

Biogas upgrading and utilization: Current status and perspectives

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ABSTRACT

Biogas production is an established sustainable process for simultaneous generation of renewable energy and treatment of organic wastes. The increasing interest of utilizing biogas as substitute to natural gas or its exploitation as transport fuel opened new avenues in the development of biogas upgrading techniques. The present work is a critical review that summarizes state-of-the-art technologies for biogas upgrading and enhancement with particular attention to the emerging biological methanation processes. The review includes comprehensive description of the main principles of various biogas upgrading methodologies, scientific and technical outcomes related to their biomethanation efficiency, challenges that have to be addressed for further development and incentives and feasibility of the upgrading concepts.

1. Introduction

Biogas is the product of a biologically mediated process, which is known as Anaerobic Digestion (AD). Biogas primarily consists of methane (CH_4) in a range of 50–70% and carbon dioxide (CO_2) at a concentration of 30–50%. The relative content of CH_4 and CO_2 in biogas is mainly dependent on the nature of the substrate and pH of the reactor. Besides these two gasses, biogas additionally contains minor amounts of other compounds, such as nitrogen (N_2) at concentrations of 0–3%, which could originate from air saturated in the influent, vapour water (H_2O) at concentrations of 5–10%, or higher at thermophilic temperatures, derived from medium evaporation, oxygen (O_2) at concentrations of 0–1%, which is entering the process from the influent substrate or leakages, hydrogen sulfide (H_2S) at concentrations of 0–10,000 ppmv, which is produced from reduction of sulfate contained in some wastestreams, ammonia (NH_3) originating from hydrolysis of proteinaceous materials or urine, hydrocarbons at concentrations of 0–200 mg/m^{-3} and siloxanes at concentrations of 0–41 mg m^{-3}, originating for example from effluents from cosmetic medical industries (Muñoz et al., 2015; Petersson and Wellinger, 2009).

Apart from CH_4, all the other gasses contained in biogas are unwanted and are considered as biogas pollutants. The energy content of methane described by the Lower Calorific Value (LCV) is 50.4 MJ/kg-CH_4 or 36 MJ/m^3-CH_4 (at STP conditions). Therefore, it is well understood that the higher the CO_2 or N_2 content is, the lower the LCV in biogas. For biogas with methane content in the range of 60–65% the LCV is approximately 20–25 MJ/m^3-biogas. H_2S and NH_3 are toxic and extremely corrosive, damaging the combined heat and power (CHP) unit and metal parts via emission of SO_2 from combustion. Moreover, the presence of siloxanes in biogas, even in minor concentrations, is associated with problems. It is well known that during combustion silicone oxides generate sticky residues which deposit in biogas combustion engines and valves causing malfunction (Abatzoglou and Boivin, 2009). Nowadays, there are different treatments targeting at removing the undesired compounds from the biogas expanding its range of applications.

The first treatment is related to “biogas cleaning” and includes removal of harmful and/or toxic compounds (such as H_2S, Si, volatile organic compounds (VOCs), siloxanes, CO, and NH_3). However, it is practically only H_2S which is mainly targeted and many current biogas plants have H_2S removal units commonly based on biological H_2S oxidation by aerobic sulphate oxidizing bacteria. The second treatment is called “biogas upgrading” and aims to increase the low calorific value of the biogas, and thus, to convert it to higher fuel standard (Sun et al., 2015). In case the upgraded biogas is purified to specifications similar to natural gas, the final gas product is called biomethane (Kougias et al., 2017b). Currently, the specifications of the natural gas composition are depending on national regulations and in some countries > 95% methane content is required; however, European Commission has recently issued a mandate for determining harmonised standards for gas quality.

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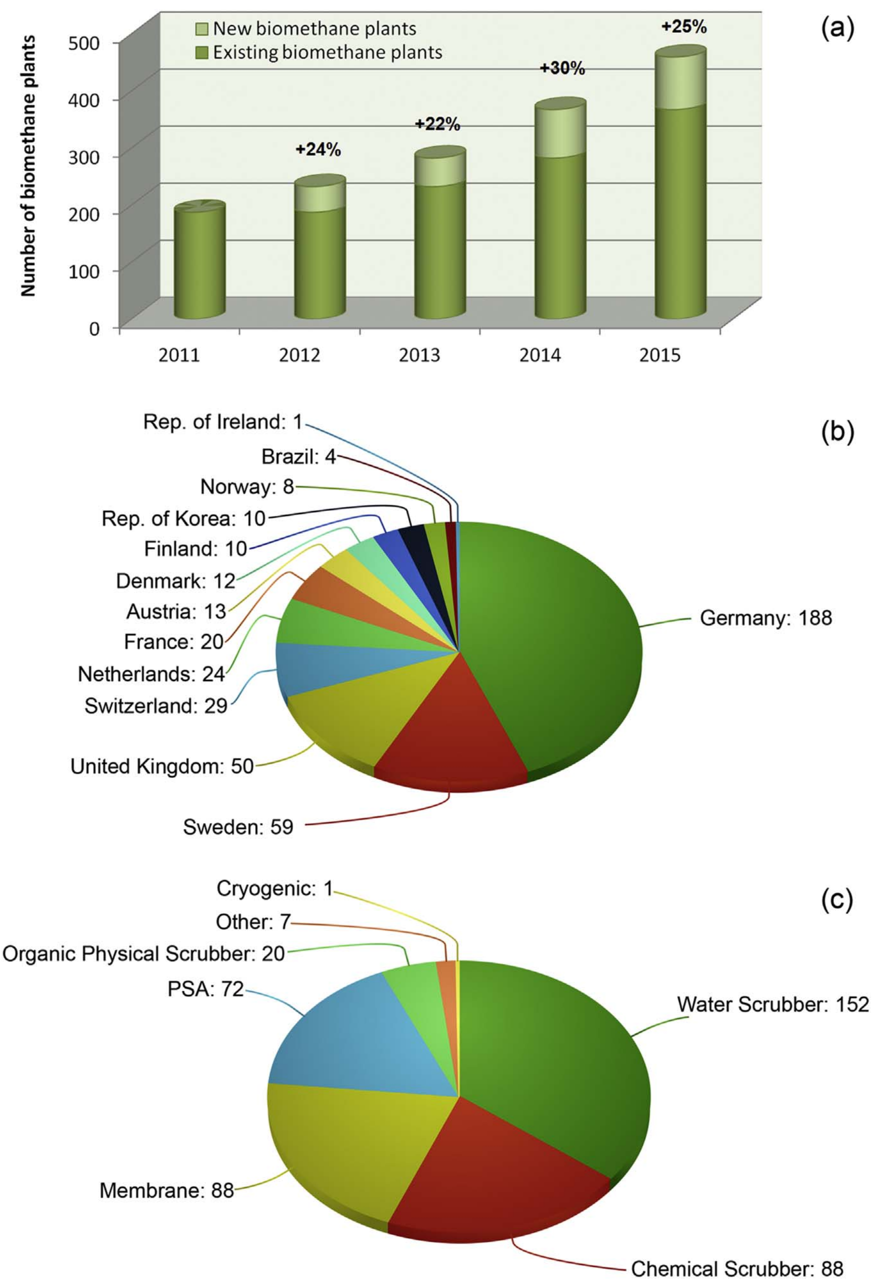

Fig. 1. Development of biogas upgrading technologies distributed according to countries and years; a) number of operating biomethane plants, b) location of existing biomethane plants and c) distribution of applied commercial technologies. Data are according to IEA Bioenergy Task 37 as reported in Hoyer et al. (2016) and European Biogas Association.

It should be noted that in the upgrading process the CO_2 contained in the raw biogas is either removed or is converted to CH_4 by reaction with H_2 (Kougias et al., 2017b). There are several commercial upgrading technologies available. An increasing number of biogas plants with biogas upgrading units are emerging in Europe the recent years (Fig. 1a). Most of the biomethanation plants are in Germany, while other European countries such Sweden, UK, Switzerland and have also constructed biomethanation facilities (Fig. 1b).

The aim of the present work is to provide a comprehensive overview of various biogas upgrading technologies and to present incentives for further development of upgrading concepts. More specifically, the review describes the main principles of commercial or under development physical, chemical and biological methodologies. Particular attention has been given to emerging upgrading bioprocesses since they are envisioned to play a protagonist role in decoupling bioenergy production from biomass availability. Finally, the review presents techno-economic and environmental incentives that encourage the sustainability perspective of biogas upgrading concepts.

2. Biogas upgrading technologies

2.1. Physical and chemical technologies

Currently, five physical/chemical technologies for separation/transformation of CO_2 from CH_4 exist at commercial readiness level (Fig. 1c), involving processes of absorption, adsorption and membrane separation. Moreover, there are other technologies based on cryogenic process or chemical hydrogenation, which are still under development. A more detailed description of the functional principles and the status of these biogas upgrading technologies is given in the next subchapters and a comparison of their biomethanation efficiencies is given at Table 1. In general, the methane recovery from physicochemical processes can reach > 96% and as it will be further discussed increased temperature, high pressure or addition of chemicals are required to ensure an efficient biomethanation.