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Techno-economic assessment of a microbial power-to-gas plant – Case study in Belgium

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HIGHLIGHTS

- The techno-economic feasibility of a microbial power-to-gas concept is analyzed.
- Energy use, operating hours and electrolysis investment are the main parameters.
- High investment costs and limited availability of renewable energy are bottlenecks.
- The business model needs to be further optimized, e.g. by working on flexibility.

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ABSTRACT

A successful transition towards a cleaner and more sustainable energy management in 2050 requires the implementation of renewable energy sources on a large scale. Therefore, it is expected that the share of renewable energy will further increase. Due to the introduction of these intermittent energy sources, the need for flexibility in our energy system increases significantly. Power-to-gas (P2G) is one promising option for providing long term energy storage and for providing flexibility to the electricity system. An interesting, recent technological development is biological methanation. The latter utilizes microorganisms to catalyze the Sabatier reaction. This biological reaction can be achieved at lower temperatures and pressures than when a chemical catalyst is used and has a higher tolerance to contaminations from the CO_2 source, process upset or contamination by foreign organisms. We investigate the techno-economic potential of biological methanation (i.e. microbial power-to-gas concept) using a case study that revolves around anaerobic digestion using mainly municipal organic waste in Belgium. The most important parameters that influence the economic feasibility are the electricity consumption (44%), operating hours of the electrolyser (14%), and the investment cost of the electrolyser (14%). Based on our findings we offer further routes of research that serve to strengthen the business case.

1. Introduction

A successful transition towards a cleaner and more sustainable energy management in 2050 requires the implementation of renewable energy sources on a large scale. Across European countries the proportion of renewable energy in total electricity production is currently very different. However, it is expected that the share of renewable energy will further increase. In these future scenarios a major role for wind and solar energy is expected [1]. These renewable energy sources are characterized by their intermittent nature, which will impact the supply security of electricity. Intermittent energy sources are energy sources that are not continuously available so that the produced renewable energy, which varies in time due to e.g. weather conditions, is not always in equilibrium with the consumers' power demand, causing an imbalance. As a consequence, on sunny, windy days, for example, electricity prices can be very low or even negative. During imbalance

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moments solutions need to be found by e.g. consuming more electricity, generating less electricity or storing the surplus electricity.

In markets with a large share of renewable energy, gas-fired electricity generation has already been used to maintain system supply and demand in balance [2]. As a consequence, power-to-gas (P2G) is gaining popularity as a solution to provide the needed flexibility to the energy system. The P2G concept is defined as the conversion of electric energy into hydrogen, i.e. using electricity in an electrolyser to split water into hydrogen and oxygen. The hydrogen can be deployed in four different ways: (i) (long term) electricity storage in case hydrogen is reconverted into electricity after buffering, (ii) the use of hydrogen as raw material in industry, (iii) the use of hydrogen as a fuel for transport, and (iv) storage of hydrogen in gas infrastructure, either by direct injection of hydrogen into the gas grid or by the conversion of hydrogen and CO_2 into methane. For example, Kötter et al. [3] investigated the impact of P2G in the implementation of the Energiewende and concluded that P2G can have an important role to reduce the levelised cost of electricity of the energy system resulting from the option of long-term energy storage. Also Qadrdan et al. [4] analyzed the role of P2G assuming different allowable levels of hydrogen injection. They concluded that the production of hydrogen from electricity decreases the overall cost of operating the gas and electricity network in Great Britain given a high share of wind power generation. Zoss et al. [5] developed a mathematical model to evaluate if wind power generation in the Baltic States would meet the need of biogas plants for methanation. They concluded that an increase in the average CH_4 content of biogas is possible, however, that not in all cases the maximum possible quality could be achieved. Grueger et al. [6] analyzed the role of P2G and re-electrification in reducing wind farm forecast errors and the ability to provide a secondary control reserve in Germany. The authors conclude that both options can be economically viable depending on the system's configuration and their operating strategy. Despite the recognition of the potential of P2G systems for our future energy system, the main drawbacks are still the relatively low efficiency and high investment cost for the electrolyser and operational costs due to the electricity price [7].

Hydrogen combined with CO_2 can be converted to methane and water, a process called methanation, which is based on the Sabatier reaction [8]. This reintegration of CO_2 into the power supply can contribute to CO_2 reduction [8]. There are several sources of CO_2 which can be considered such as biomass, flue gases from power plants and biogas or even from direct air capture, CO_2 from gas upgrading being the cheapest source [9]. Furthermore, Meylan et al. [10] developed a methodology to assess the carbon balance of power-to-gas and concluded that biogenic and atmospheric CO_2 are most interesting because of their low greenhouse gas emissions. They indicate that using CO_2 from fossil resources might make sense during a transition period as emissions are saved. Methane can be used in several applications. It can be stored, transported and can be converted back into electricity. In some countries, such as Germany, there are projects ongoing where hydrogen or methane formed from hydrogen are injected into the natural gas grid [7]. This conversion is mostly done by the (physico-chemical) Sabatier reaction in which high pressures, high temperatures and catalysts are required [11,12].

Another interesting development in methanation methods is the so-called biological methanation. This approach utilizes microorganisms, more specifically hydrogenotrophic methanogenic archaea, to catalyze the Sabatier reaction [9]. This can be achieved at lower temperatures than when a chemical catalyst is used [13,14]. It also has a higher tolerance to contaminations, such as organic acids and H_2S [15,16]. The conversion of H_2 and CO_2 to CH_4 can be achieved in various types of reactor designs. In most of the reactors the reaction chamber is filled with liquid or moist solid particles. Other researchers used a trickle-bed reactor, in which the reaction chamber was not filled with liquid [15,17], but instead they immobilized the microorganisms on the surface of a packed bed and sprinkled them with a limited amount of liquid, resulting in better material transport and higher efficiency of the system. Although there is a large interest in the methanation of CO_2, many questions about catalysts and biological methanation remain unresolved, but interest in the process has incited further research [15,18,19].

When developing innovative technologies, such as biological methanation, it is important to have a clear idea on the economic performance of the process. Therefore, in this study we performed a techno-economic assessment (TEA) to optimize the development of the process and to determine the most important parameters. Techno-economic studies have previously been performed for different P2G systems [20,21]. For example, Parra et al. [21] concluded that P2G systems in Switzerland generating hydrogen and synthetic natural gas (SNG) are not economically competitive with conventional gas production systems if only hydrogen and SNG are sold. Collet et al. [20] performed a techno-economic and life cycle assessment of methane production in France using a combination of anaerobic digestion of sewage sludge and power-to-gas technology. They concluded that the price of electricity influences to a large part the competitiveness of the system with injection of methane from biogas. Schiebahn et al. [1] indicated that the production cost of renewable hydrogen or methane in Germany is several times higher than the cost of natural gas. Therefore, they argue that the usage of renewable hydrogen is more interesting in the transport sector. Kopp et al. [22] concluded that hydrogen production in Germany using a Proton Exchange Membrane (PEM) electrolyser is most interesting when participating in the secondary control reserve market. Furthermore, they identified the capital costs, fixed costs and efficiency as important parameters to further improve the economic feasibility of the system. Most of the existing studies focus on chemical P2G systems, but studies investigating the techno-economic feasibility of biological methanation are only limited. Götz et al. [7] compared both catalytic and biological methanation and concluded that biological methanation is most interesting for small plant sizes. Furthermore they indicate the low temperature and high tolerance of impurities as advantages of the microbial system. The disadvantage is the large reactor volume that is required. Recently, Pääkkönen et al. [23] published a research on the techno-economic feasibility of a microbial power-to-gas system and concluded that the main parameters influencing the economic feasibility are the investment cost of the electrolyser and the biomethane price. Vo et al. [24] determined the minimum selling price of biomethane for three scenarios, i.e. biogas upgrading through amine scrubbing, biogas upgrading through amine scrubbing and ex-situ biological methanation and biogas upgrading directly through ex-situ biological methanation. They concluded that biogas upgrading directly through ex-situ biological methanation is financially more interesting compared with amine scrubbing in combination with ex-situ biological methanation. Furthermore, they concluded that the cost of hydrogen significantly influences the minimum selling price of the methane. In this paper we report the results of a case-study for biological methanation (further called microbial P2G concept) in a Belgian context, aiming to identify the economic feasibility and the main influencing parameters of the microbial P2G concept. In Belgium several anaerobic digesters (mainly using agricultural waste and some using organic municipal solid waste (OMSW)) are installed. According to the yearly report of 2016 provided by Biogas E vzw (i.e. platform for anaerobic digestion in Flanders) 41 digesters were running in Belgium. The state-of-the-art technology for processing OMSW is evolving from composting, to predigestion followed by composting. Currently many of the digesters face financial difficulties and are searching for alternative business models [25]. In Flanders, biogas upgrading systems have not been installed yet. This option will especially be interesting for OMSW digesters to improve the business case as these installations do not have a high local heat demand. Furthermore, we see an increased amount of renewable energy, with a yearly increase in the amount of energy produced by wind mills and solar panels [26]. Taking into account the number of digesters, the increasing interest in