Applied Energy 125 (2014) 84–92

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Uncertainty over techno-economic potentials of biogas from municipal solid waste (MSW): A case study on an industrial process

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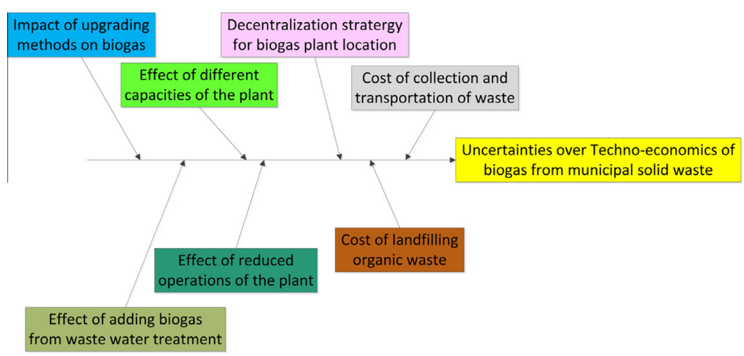
HIGHLIGHTS

- Uncertainties affecting profitability of biogas from OMSW was evaluated.
- Collection and transportation costs affect the profitability.
- The bigger the plant, the more energy and economic efficient it is.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 October 2013
Received in revised form 28 February 2014
Accepted 20 March 2014

Keywords:
Biogas
Techno-economic analysis
MSW
Vehicle fuel
Process design

ABSTRACT

In this study, biogas production from the organic fraction of the MSW (OMSW) was simulated in six different scenarios, using Aspen Plus® based on industrial data. The economic evaluations were made using the Aspen process economic analyzer, considering the plant size and the upgrading methods. The base case had an annual processing capacity of 55,000 m^3 OMSW. The capital costs and the net present value (NPV) after 20 years of operation were 34.6 and 27.2 million USD, respectively. The base case was compared to the modified scenarios, which had different upgrading methods, processing capacities, addition of biogas from wastewater sludge treatment, and variation of the substrate (OMSW) between ±200 USD/ton. The sensitivity analyses were carried out considering the cost of the OMSW imposed on citizens for collection and transportation of wastes and the different sizes of the plant. The result suggests that producing biogas and selling it, as a vehicle fuel from OMSW is a profitable venture in most scenarios. However, there are some uncertainties, including the collection and transportation costs, landfilling fee, and process operation at lower capacities, which affect its profitability.

1. Introduction

The annual generation of municipal solid waste (MSW) has attained more than 2.5 billion tons per year [1]. More than 50% of the MSW ends up in dumping areas or landfills, creating three major problems: (a) loss of fertile or arable land, (b) health hazard, and (c) loss of energy and materials from the waste. Approximately 50% of the MSW is composed of organics in the world, which can be converted into value-added products such as biogas or

Abbreviations: MEA, monoethanol amine; COOAB, carbon dioxide absorption by amine; MSW, municipal solid waste; HRT, hydraulic retention time; OLR, organic loading rate; CSTR, continuously stirred tank reactor; TS, total solids; MMSP, minimum methane selling price; APC, annual processing capacity; CHP, combined heat and power; CBG, compressed biogas; PBP, payback period; NPV, net present value; IRR, internal rate of return; WWTP, wastewater treatment plant.

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http://dx.doi.org/10.1016/j.apenergy.2014.03.041
0306-2619/

composts [2]. While the aerobic biodegradation in composting results only in CO_2 and fertilizer, biogas from anaerobic digestion contains about 50–70% methane and the rest is practically CO_2. Energy-rich methane (~37 MJ/m^3) can be used for different purposes including heat, electricity, and vehicle- and cooking fuels [3]. It can be calculated that the MSW with an average 33% total solids (TS) content can result in 321 billion m^3 pure methane from the global MSW production, based on the average biogas yield of 618 m^3/ton TS. The 321 billion m^3 methane is equivalent to 3104 TW h/year energy (1 m^3 methane equivalent to 9.67 kW h) [4], which is equivalent to 2% of the global energy consumption per year.

Several million *bio-digesters* for households are available in the world, while industrial biogas plants for commercial applications such as electricity and fuel are relatively few [5,6]. According to International Energy Agency, about 970 plants are in operation for municipal solid waste and industrial waste together in Europe [7]. Very few plants produce methane for vehicle fuel as compressed biogas (CBG); on the contrary, most of the plants produce power or combined heat and power (CHP) from biogas [8]. Biogas from the organic fractions of MSW is not only attractive in terms of energy, but also economically sound. The capital costs of the biogas plants treating 100,000 tons MSW/year was 20 million USD in 2003 [9]. Upgrading the produced biogas to vehicle fuel requires about 13% of the total investment costs [9,10].

Techno-economic models are used as a measure to identify the industrialization potential of a project. Several techno-economic models have been reported for ethanol production; however, for biogas, the literature is mainly based on laboratory data with novel substrates such as citrus wastes, chicken-feather, and its pretreatments [8,11–17]. According to our knowledge, no industrial based biogas plants have been considered for techno-economic evaluation of MSW. The techno-economic evaluation considered in this study was based on an industrial biogas plant located in Borås (Sweden) that is fed with sorted organic MSW.

Borås, with a population of more than 100,000 people, produces on average about 22,600 tons of MSW every year. In addition, the MSW from Norway and other nearby Swedish cities such as Gothenburg, and the industrial wastes from companies, slaughterhouses, restaurants, etc., also end up in the waste station in Borås. Approximately, 27% of the MSW is recycled as materials, 30% (organic wastes) is sent for biological treatment for the production of biogas, and the remaining 43% is combusted to produce electricity and district heat for the city. The biogas produced after the biological treatment is used as CBG for vehicle fuel to run buses, garbage trucks, and other gas vehicles [18,19].

In this study, the techno-economic feasibility of an industrial biogas plant for MSW, located in Borås, Sweden was investigated under six different scenarios. The process was simulated using Aspen Plus® version 8.0 (AspenTech, Massachusetts, U.S.A.) based on the industrial data obtained from Borås Energy and Environment AB, Sweden. The six different scenarios were simulated using Aspen Plus®, and process economics were carried out using the Aspen Process Economic Analyzer (V 8.0). Furthermore, sensitivity analysis was carried out for different costs of the MSW, which varied between ±200 USD/ton, number of digesters operating in the plant, and effect of operational loading in the plant. The main objective of this work was to study the uncertainties around the techno-economic feasibility of the biogas production from OMSW, affected by factors mentioned above.

2. Methods

2.1. Process description

The process scheme for the six scenarios is shown in Fig. 1. The six different scenarios considered were based on the current operation of the plant (*scenario 1*), and *scenarios 2* and *3* were considered to facilitate different upgrading methods and the effect of adding biogas from wastewater treatment respectively. The other three scenarios considered were to double the capacity, to check how the size or the number of digester used, and their effects on the process profitability. *Scenarios 1–3* have a capacity of 55,000 m^3 MSW/year, while *scenarios 4–6* have a base capacity of 110,000 m^3 MSW/year. In this study, *scenario 1* is the base case, which will be compared to other scenarios. The total solids (TS) content of the MSW fed to the digester was 15%. The preprocessing step for the MSW was common under all scenarios, while the digesters and the biogas upgrading to obtain methane vary for the different scenarios.

Initially, the MSW is crushed using a hammer mill crusher with the addition of water, to reduce the particle size to less than 5 mm. The TS of the MSW is reduced from 33% to 15% with the addition of water. The crushed materials are transported using a centrifugal pump to two storage tanks, buffer tanks 1 and 2, with a respective volume of 200 m^3 and 650 m^3, which have a combined retention time of 3 days. Then, the waste slurry is pumped into a 3000-m^3 anaerobic digester. *Scenarios 1–3* have a single digester, whilst *scenarios 4–6* have two digesters of the same volume running in parallel. The organic loading rate (OLR) maintained in the digester is 3.3 kg_{VS}/m^3/day with a hydraulic retention time (HRT) of 19 days. The digesters operate at 55 °C, heated internally.

The digestate from the digester is pumped into a 340-m^3 storage tank with a retention time of 2.2 days. The digestate is further pumped into a big storage tank of 2000 m^3, from where it is transported to nearby farmlands. Part of the biogas is produced from the storage tank. All the biogas production is connected to a common upgrading system. The upgrading methods used in this study are water scrubbing and absorption through COOAB (carbon dioxide absorption by amine) using monoethanol amine (MEA). Water scrubbing is a common upgrading method for biogas, while in the COOAB process MEA is used for the absorption of carbon dioxide and hydrogen sulfide. The raw biogas flowing out of the digester passes through a centrifugal compressor to increase the pressure to 8 bar, and is then cooled down to 5 °C using a heat exchanger, before it passes through the upgrading column either by water scrubbing or COOAB [4].

The scrubber column operates at 8 bar, where the CO_2 is removed with the water. The recycling ratio in the scrubber for water was maintained at 0.90. Similarly, the absorption column for the COOAB process was operated at 5 bar. The recycling ratio of the MEA in the absorption column was 0.95. Purified methane (~97%) is sent through another separator to remove final impurities. Thereafter, the CBG (compressed biogas with 99% purity of methane) is stored at 5 °C and 300 bar, before it is sold to the market as car fuel. The CBG is sold at a price of 2.2 USD/L, including 0.4 USD/L tax, resulting in the industry selling CBG at a net price of 1.81 USD/L (Table 1).

Based on the aforementioned processes, six scenarios (Fig. 1) were compared, as follows:

Scenario 1: annually, 55,000 m^3 MSW is used with one digester in operation. The upgrading method employed was COOAB only. This scenario was considered as the base case scenario (currently in existence at the plant), which was compared to other scenarios. Fig. 2 shows the process flow diagram for the base case.

Scenario 2: similar to scenario 1, but the upgrading method was water scrubbing.

Scenario 3: in this scenario, the same amount of waste was used; however, the biogas was upgraded by both water scrubbing (30%) and the COOAB process (70%). In addition, 3500 m^3/day biogas was added, which was obtained from the