Energy 79 (2015) 298–309

Contents lists available at ScienceDirect

Energy

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

Explorative economic analysis of a novel biogas upgrading technology using carbon mineralization. A case study for Spain

Katherine Starr [a, *], Andrea Ramirez [b], Hans Meerman [b], Gara Villalba [c], Xavier Gabarrell [c]

[a] Sostenipra, Department of Chemical Engineering, Universitat Autonoma de Barcelona, Bellaterra, Spain
[b] Copernicus Institute, Utrecht University, 3584 CS Utrecht, The Netherlands
[c] Sostenipra, Institute de Ciència i Technologia Ambientals (ICTA), Department of Chemical Engineering, Xarxa de Referencia en Biotechnologia (XRB) de Catalunya, Universitat Autonoma de Barcelona, Bellaterra, Spain

ARTICLE INFO

Article history:
Received 14 May 2014
Received in revised form
4 November 2014
Accepted 5 November 2014
Available online 29 November 2014

Keywords:
Biomethane
CCS (carbon capture and storage)
Biogas upgrading
Carbon mineralization
Annual net benefit

ABSTRACT

This paper studies the potential application of a novel biogas upgrading technology called alkaline with regeneration (AwR). This technology uses an alkaline solution, along with carbon mineralization, to remove and store CO_2 from biogas in order to create biomethane, a substitute of natural gas. Three different applications of biogas were explored for their potential economic benefits along three different biogas generation capabilities of landfills in Spain (250 Nm^3/h, 1000 Nm^3/h and 5000 Nm^3/h). The scenarios include upgrading biogas using AwR and injecting the biomethane into the natural gas grid, or selling the gas as a vehicle fuel. The third reference scenario assessed directly burning the biogas for the production of electricity. The latter showed an annual profit of 0.2–5 million $€_{2012}$ while upgrading the biogas to obtain biomethane showed an annual loss of 3–50 million $€_{2012}$. This was due to the operational costs involved in AwR, namely the cost of NaOH (principal reagent) and the treatment of wastewater. Increasing revenue can help obtain an annual profit. In order to break-even it would be necessary to raise CO_2 credits to 99 $€_{2012}$/t or, through feed in tariffs, increase the price of the sale of biomethane to 0.25 $€_{2012}$/kWh.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

It is predicted that in the year 2020 Europe will produce 10 billion m^3 of biomethane solely from the biogas of landfills [1]. While this biogas can be considered as an environmental contaminant due to its high concentrations of methane (CH_4) (35–65%) and carbon dioxide (CO_2) (15–50%) [2,3], for the same reasons it can be considered as a potential source of energy. CH_4 is a powerful greenhouse gas (GHG) that is 34 times more potent than CO_2 in trapping heat in our atmosphere [4] and therefore concerns have been raised in minimizing such emissions [5,6]. Furthermore, as it has a high calorific value it is also a potential source of energy. By removing the CO_2 from biogas through the application of carbon capture technologies, it is possible to obtain a high concentration of methane, often referred to as biomethane, which is comparable to commercial natural gas. This allows for biogas to become a potential source of alternative natural gas, and can therefore have the same uses as natural gas. In this paper attention is focused on two of those uses, as a fuel for vehicles or it could be fed into the natural gas grid.

The application of carbon capture to biogas in order to form biomethane is called biogas upgrading. While it utilizes carbon capture technology it does so at a smaller scale than what is currently envisioned when referring to carbon capture (for example power plants). This smaller scale also allows for the deployment of novel capture techniques which have not yet been tested on or proved at a larger scale. One such example is carbon mineralization. This process has been gaining interest as a viable route for carbon storage [7–9] as it uses a chemical reaction to convert the CO_2 into a non-soluble solid compound. Materials that contain metal oxides (such as calcium oxide (CaO) or magnesium oxide (MgO)) are put in contact with CO_2. The metal oxides react with the CO_2 to form a carbonate (calcium carbonate ($CaCO_3$) or magnesium carbonate

Abbreviations: APC, air pollution control; AwR, alkaline with regeneration; GHG, greenhouse gas.

* Corresponding author. Department of Chemical Engineering, Edifici Q, Universitat Autonoma de Barcelona (UAB), E-08193 Bellaterra, Cerdanyola del Valles, Barcelona, Spain. Tel.: +34 93 581 4796; fax: +34 93 581 2010.

E-mail addresses: Katherine.Starr@uab.cat (K. Starr), c.a.ramirez@uu.nl (A. Ramirez), J.C.Meerman@uu.nl (H. Meerman), gara.villalba@uab.cat (G. Villalba), Xavier.gabarrell@uab.cat (X. Gabarrell).

http://dx.doi.org/10.1016/j.energy.2014.11.015
0360-5442/© 2014 Elsevier Ltd. All rights reserved.

($MgCO_3$)). Metal oxides occur naturally in minerals such as silicate, serpentine and olivine. High levels of CaO can also be found in industrial wastes such as air pollution control (APC) residues from municipal solid waste incinerators [10]. While the composition of APC residues can vary greatly, the residues are mainly made up of fly ash, chlorine based salts and inorganics such as heavy metals (which can leach resulting in APC being classified as a hazardous waste) [11]. They also contain calcium hydroxide ($Ca(OH)_2$) at around 36% (w/w) which is reactive with CO_2 [12]. There has been growing interest in using carbon mineralization for biogas upgrading and one such technique that is being developed is called *alkaline with regeneration* (AwR) [13,14]. This process uses an alkaline solution to strip CO_2 from biogas and then this solution passed through the APC residues in order to store the CO_2 while at the same time regenerate the alkaline solution. This technology, currently at the pilot plant stage, presents an advantage over current biogas upgrading technologies as it stores CO_2 while it captures it.

There are currently six biogas upgrading technologies that are on the market, which include high pressure water scrubbing, chemical scrubbing with amine, pressure swing adsorption, cryogenic separation, membrane separation and organic physical scrubbing. These technologies all help isolate methane by capturing impurities such as CO_2 from the biogas stream. However, currently most captured CO_2 is released back into the atmosphere as the conditions necessary to create a business case are not present (availability of transport infrastructure, market uses of CO_2 at the right location, etc.). Interest has been growing in biogas upgrading technologies and various facilities exist. While biogas upgrading has been applied to certain regions such as Germany and Sweden, their application has however not been very widespread [2,15]. Application of biogas upgrading technologies focuses on facilities that have anaerobic digestion of organic matter, e.g., agricultural facilities that deal with waste crops and manure, and waste treatment facilities such as wastewater treatment, anaerobic digestion of municipal solid waste and landfills for municipal solid waste. The latter of which is the focus of this article. The biogas produced from each source differs in its final composition due to the differences in its input. Meanwhile pre-cleaned non-upgraded biogas can be burned directly for electricity (for example in a gas generator or CHP (combined heat and power)). When it is upgraded the biomethane is an alternative source of natural gas and can therefore be injected into the natural gas grid, or be used as a vehicle fuel, all of which could bring a profit to the owner of the biogas upgrading facility.

The novel technology, AwR, poses an interesting issue in that it can be profitable while capturing and storing CO_2 at the same time. Though as this technology is still at the pilot plant stage it is important to review whether the application of this technology can be economically feasible and where focus should be placed in order to maximize profits. Therefore this article explores the potential application of AwR in three different landfill sizes in Spain, with increasing biogas generation, and explores the potential costs involved in the upgrading and injection into the gas grid, as well as selling it as vehicle fuel.

2. Methodology

This article follows a techno-economic study conducted by Lombardi and Carnevale [16] in which the total cost of a 250 Nm^3/h AwR facility, under different working conditions (applying reuse of wastewater, as well as varying base type and concentration) in Italy, was determined [16]. This article looks to apply the AwR technology, which was determined to have the lowest specific cost, in landfills in Spain and examine under which economic conditions and technological scale a profit can be obtained by selling biomethane for different final applications. As the technology is still in the pilot plant stage, and considering the time needed to upscale to operational level, it is assumed that the upgrading facility will become operational in 2025.

In this section the following will be discussed: the technical details of AwR, the different scenarios under review, and the economic model that was used.

2.1. Technical information

The technology under review is the alkaline with regeneration (AwR) process (Fig. 1). During the development of this technology there were various different combinations of working conditions that could be applied. It was decided to select the working condition that presented the lowest environmental impact for this technology [17], which is AwR using a 10% concentration of NaOH and re-using the wastewater. This working condition was also found to have the lowest annual cost in the study by Lombardi and Carnevale [16].

In this process, water and NaOH are first mixed to form a solution of 10% concentration by mass.[1] This is passed through a packed column in which the biogas is pumped through. The CO_2 absorbs to the NaOH according to equation (1) and the biogas is upgraded. The resulting CH_4 rich gas leaves the system.

$$2NaOH_{(aq)} + CO_{2(g)} \rightarrow Na_2CO_{3(aq)} + H_2O_{(l)} \quad (1)$$

The loaded solution is then pumped into a mixer that is filled with APC residues that has been prewashed and filtered to remove the heavy metals and chlorine [16]. The resulting wastewater is sent for treatment and disposal. The sodium carbonate (Na_2CO_3) reacts with the $Ca(OH)_2$ to form $CaCO_3$ as seen in equation (2). Meanwhile, the NaOH solution is regenerated at a rate of 61%. The slurry is removed and fresh APC that has been prewashed is placed into the mixer.

$$Na_2CO_{3(aq)} + Ca(OH)_{2(s)} \rightarrow CaCO_{3(s)} + 2NaOH_{(aq)} \quad (2)$$

The slurry is passed through a filter to separate the regenerated NaOH solution and the carbonated APC residues. The regenerated NaOH solution is pumped back into the column, along with the necessary make-up of water and NaOH (39% make-up solution is required). The carbonated APC residues are then post-washed to remove any excess alkaline solution and this wastewater is sent back into the process as the water to pre-wash the APC residues.[2] The carbonated APC residues have an improved leaching behaviour and therefore can be disposed of and treated as non-hazardous waste [11].

2.2. Conditions and scenarios

Three cases were selected for potential biogas generation, based on landfill data in Spain [18] and standard sizes of conventional biogas upgrading technologies [2]. The first case is a generic landfill that generates 250 Nm^3/h of biogas, which is the size at which the developers of AwR focused their study [16] and can be considered as a mid-range biogas collection rate. The second case is a generic landfill that generates 1000 Nm^3/h which is found generally in

[1] Other variants of the process, not examined in this study, include using KOH instead of NaOH and using NaOH at 13% concentration.

[2] A variant of the process, not examined in this study, includes sending the wastewater generated from the post-washing directly to be treated at a wastewater treatment facility, as opposed to reusing it for the pre-washing.

Download English Version:

https://daneshyari.com/en/article/8075855

Download Persian Version:

https://daneshyari.com/article/8075855

Daneshyari.com