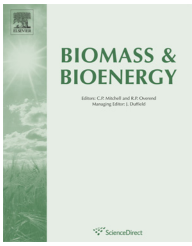
Available online at www.sciencedirect.com

ScienceDirect

http://www.elsevier.com/locate/biombioe



Utilization of surplus electricity from wind power for dynamic biogas upgrading: Northern Germany case study

Lars Jürgensen [a,*], *Ehiaze Augustine Ehimen* [a,1], *Jens Born* [b,2], *Jens Bo Holm-Nielsen* [a,3]

[a] *Aalborg University Esbjerg, Niels Bohrsvej 8, 6700 Esbjerg, Denmark*
[b] *Flensburg University of Applied Science, Kanzleistr 91-93, D-24937 Flensburg, Germany*

ARTICLE INFO

Article history:
Received 10 September 2013
Received in revised form
18 February 2014
Accepted 28 February 2014
Available online xxx

Keywords:
Methanation
Sabatier reaction
Surplus electricity
Germany
Biogas
Upgrading

ABSTRACT

The methanation of CO_2 has been increasingly discussed for the potential long term storage of electricity and for facilitating grid load management. Using the regions of northern Germany as a case study, the feasibility of CO_2 conversion from biogas plants and its integration in existing natural gas grid was examined in this study. Furthermore the material and energy flows of in the methanation process, were evaluated to provide expression for the quantities of excess electrical energy which could be potentially stored using the biogas integrated systems. The study results showed that with 480 biogas plants in the region would be able to utilize up to 0.7 TWh surplus electricity could be used to produce 100 10^6 m^3 at standard temperature and pressure of upgraded methane per year.

1. Introduction

By 2050, 80% of the electricity demand in Germany is forecasted to be met using renewable resources [1]. Currently, 20% of electricity produced countrywide is obtained from renewable energy (RE) systems with growth rates of 17% observed in 2011 compared with 2010. Wind power has been reported as the leading RE resource for electricity production with 46.5 TWh (7.6 %of the total electricity production in Germany) generated in 2011 [2]. A major problem with the use of such RE systems is that unlike traditional power plants where outputs could easily be adjusted to match consumer power requirements, these systems rely heavily on highly transient energy sources and are thus characterized by distinct short term and seasonal power output variations [3]. This power difference is of interest in this paper, and is what is

---

[*] *Corresponding author*. Flensburg University of Applied Science, Kanzleistr. 91-93, D-24937 Flensburg, Germany. Tel.: +49 176 65335730.
E-mail addresses: Lars.juergensen@fh-flensburg.de (L. Jürgensen), ehiaze.ehimen@vito.be (E.A. Ehimen), Jens.born@fh-flensburg.de (J. Born), jhn@et.aau.dk (J.B. Holm-Nielsen).

[1] Present address: Seperation and Conversion Technology, Flemish Institute for Technological Research (VITO), Boeretang 200, 2400 Mol, Belgium. Tel.: +32 1433 6980.

[2] Tel.: +49 461 805 1293.

[3] Tel.: +45 9940 3317.

http://dx.doi.org/10.1016/j.biombioe.2014.02.032
0961-9534/

Please cite this article in press as: Jürgensen L, et al., Utilization of surplus electricity from wind power for dynamic biogas upgrading: Northern Germany case study, Biomass and Bioenergy (2014), http://dx.doi.org/10.1016/j.biombioe.2014.02.032

subsequently referred to as *excess* or *surplus* electricity or power. 421 GWh (127 GWh) of surplus electricity was reported to be available in Germany in 2011 (2010) [4,5] with a large contribution from wind power, and this figure is expected to increase to 1.1–13 TWh by 2020 [6,7]. The wide range of expected surplus power results from the different future energy mixes sceneries assumed by the calculations in those studies. This rapid increase is expected to be caused by the continuous growth of renewable energy production in Germany, especially off-shore wind power production. Just in the state of Schleswig–Holstein, the most northern state of Germany, the available surplus electricity due to feed-in management doubled every year from 2009 to 2011 [8]. The application of energy storage technologies are therefore necessary as an important factor which would enhance the reliability of RE generation systems.

Previous scientific studies have highlighted the advantages of using hydrogen as renewable energy carrier. Hydrogen however has some disadvantages, like its low volumetric energy density and a lack of existing infrastructure for storage and utilization [7]. Using the Sabatier reaction (see eq. (1)) hydrogen can be converted into methane, which already plays an established role in present energy systems as natural gas. The energy loses during the Sabatier reaction can be outbalanced by the advantages of the usage of methane (CH_4). Conversely, using the proposed biogas upgrading scheme, the biogas carbon dioxide (CO_2) content is converted to CH_4 by the Sabatier process, with hydrogen (H_2) as a process input:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad \Delta H^0 = -167\ \mathrm{kJ/mol} \tag{1}$$

The Sabatier reaction is usually catalyzed by Nickel and Ruthenium catalysts [9,10]. The chemical equilibrium of this reaction is far on the right hand side [11,12] and experimental investigations have shown that CO_2 and H_2 can be nearly completely converted with selectivity close to 100% [13].

However, there appears to be limited case studies on the feasibility and use of biogas upgrading as a route for storing excess electricity and for power demand management.

Besides the goal of 80% renewable electricity production, the German Federal Government had established by law a goal of injecting $6 \cdot 10^9$ m^3/a of upgraded biogas (as CH_4) into the natural gas grid by the year 2020 [14]. In 2011, a 4.6% accomplishment of this goal was achieved, with an increase to 7.9% of the set targets observed in 2012. Technologies which could be applied to help boost the gas grid supply and hence the attainment of these goals would therefore be beneficial.

Expressions for the estimation of the amount of electrical energy which could potentially be stored using biogas systems will be presented in this study. Furthermore, using the four most northern counties of Germany as a case study, an assessment of the excess power quantities which could be stored regionally using the proposed storage scheme will also be presented. In addition, the existing natural gas grid structures were also examined to check its use for the injection and transport of the upgraded CH_4.

Depending on the feedstocks used and digestion conditions, biogas is mainly composed of CH_4 and CO_2. With the proposed upgrading route, an increase in the CH_4 outputs from the biogas plant can be facilitated by a conversion of the biogas CO_2 fractions to CH_4. To characterize and determine the efficiencies associated with the use of the biogas upgrading route as a potential excess grid power storage system, the material and energy flows were thus initially used as a basis to derive correlations between the electrical power output P_{el} of the CHP unit of a conventional biogas production plant and the excess grid or convertible power input P_{sur}.

2. Methodology—dynamic biogas upgrading

2.1. *Process setup and technology*

The term *dynamic biogas upgrading* refers to a process which can be switched between two process states: (i) during hours of electricity demand the anaerobic derived biogas is utilized in a internal combustion engine for CHP generation and (ii) as soon as there is no demand for electricity production the process is switched to the upgrading route to produce upgraded biogas. The upgraded high CH_4 gas output from the process can thus be considered as a biological substitute natural gas (bio-SNG) which can be supplied into existing natural gas grids.

The application of the dynamic upgrading process is in contrast to conventional static biogas upgrading, which is mainly achieved by the reduction or removal of the biogas CO_2 fraction by absorption (i.e. via water or chemical scrubbing), adsorption (i.e. pressure swing adsorption, PSA), or membrane separation methods. Such upgrading methods are currently widely applied in biogas production facilities [15–18].

For this study, it was assumed that only biogas plants equipped with CHP conversion systems will be considered to use the proposed scheme. With that assumption the upgrading process is thus dynamic with respect to two process states:

1. During periods of electricity demand the CHP generates electricity P_{CHP} and heat $\dot{Q}_{CHP}$ from the biogas resulting from the anaerobic digestion process (Fig. 1a).
2. During periods of excess wind energy, the surplus electricity from renewable energies P_{sur} is used for the production of hydrogen (via electrolysis). The hydrogen is then used for the conversion of the biogas CO_2 content to bio-SNG using the Sabatier process (Fig. 1b).

The implementation of the dynamic biogas upgrading scheme would therefore provide opportunities for: (i) the use of the produced gas for bio-SNG production, (ii) the exploitation of the exothermic reaction of the upgrading process for heat supply to connected consumers, and (iii) switching between both process, where positive and negative control power is provided to the electrical power grid operator.

The technologies associated with the dynamic biogas upgrading are not novel. The Sabatier process has been demonstrated since the early 1900's and applied in an industrial scale since the 1960's for the removal of CO_2 from ammonia synthesis gas streams [19,9]. The process has further recently found significant interest in space applications, with its use as an energy storage tool [20,21]. For the latter use, it is necessary to develop quick responding reactors and/or process setups which is part of current research in our and other groups [22,23].

Please cite this article in press as: Jürgensen L, et al., Utilization of surplus electricity from wind power for dynamic biogas upgrading: Northern Germany case study, Biomass and Bioenergy (2014), http://dx.doi.org/10.1016/j.biombioe.2014.02.032