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Comparison of global warming potential between conventionally produced and CO_2-based natural gas used in transport versus chemical production

Wieland Hoppe [a, *], Stefan Bringezu [a, b, 1], Nils Thonemann [c, 2]

[a] Center for Environmental Systems Research, University of Kassel, Wilhelmshöher Allee 47, D-34117 Kassel, Germany
[b] Wuppertal Institute for Climate, Environment and Energy, Döppersberg 19, D-42103 Wuppertal, Germany
[c] University of Göttingen, Platz der Göttinger Sieben 5, D-37073 Göttingen, Germany

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ABSTRACT

In the future, the capacities of renewable SNG (synthetic natural gas) will expand significantly. Pilot plants are underway to use surplus renewable power, mainly from wind, for electrolysis and the production of hydrogen, which is methanated and fed into the existing gas pipeline grid. Pilot projects aim at the energetic use of SNG for households and transport in particular for gas fueled cars. Another option could be the use of SNG as feedstock in chemical industry.

The early stage of development raises the question of whether SNG should be better used for mobility or the production of chemicals. This study compares the global warming potential (GWP) of the production of fossil natural gas (NG) and carbon-dioxide (CO_2)-based SNG and its use for car transport versus chemical use in the form of synthesis gas. Since the potential of wind energy for SNG production is mainly located in northern Germany, the consequences by a growing distance between production in the North and transport to the South of Germany are also examined.

The results indicate that CO_2-based SNG produced with wind power would lead to lower GWP when substituting NG for both uses in either transport or chemical production. Differences of the savings potential occur in short-distance pipeline transport. The critical factor is the energy required for compression along the process chain.

1. Introduction

The transformation of the energy system from fossil and nuclear energies towards renewables is a central goal of the German energy policy. The so-called "Energiewende" leads to several changes in the distribution and use of energy. The shift from a fossil based to a wind and solar based energy production requires in particular improved systems for energy storage (Davis and Martín, 2014).

Carbon dioxide (CO_2)-based natural gas (synthetic natural gas, SNG) may be an option for energy storage, in particular for wind power which cannot be directly used in the form of electricity (Yang and Wang, 2015).

SNG can be produced by methanation of CO_2 (1), a reaction first described by Sabatier in 1902:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O(-253\text{kJ/mol}) \quad (1)$$

In contrast to Carbon Capture and Storage (CCS) as described in Zhu et al. (2015) or Kainiemi et al. (2015), CO_2 is not stored as waste in the ground, but rather used as carbon source for methane. Considering this fact, CO_2 has a value. This is why the economic and social barriers for implementing the use of CO_2 as raw material could be lower than for CCS in the future (Wennersten et al., 2015).

SNG offers different options for use. It can be used as energy source for electricity or heat production, as transport fuel or as feedstock for chemical production. The potentially growing production capacity of SNG raises the question of whether its production and use lead to lower emissions of greenhouse gas emissions than NG. Moreover, it should be clarified whether SNG should be better used as transport fuel or in chemical production in terms of environmental impact.

* Corresponding author. Tel.: +49 561 804 6151.
E-mail addresses: wieland.hoppe@uni-kassel.de (W. Hoppe), stefan.bringezu@wupperinst.org (S. Bringezu), nils.thonemann@wiwi.uni-goettingen.de (N. Thonemann).
[1] Tel.: +49 202 2492 131.
[2] Tel.: +49 551 39 4479.

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In 2014, Germany was supplied with NG from Russia (35.4%), Norway (30.4%), the Netherlands (22.1%), domestic production (8.2%) and other countries (3.9%) (Bundesamt für Wirtschaft und Ausfuhrkontrolle, 2015; Wirtschaftsverband Erdöl- und Erdgasgewinnung e.V., 2015). The quality steps of NG processing depend on its regions of origin. After its processing (separation of H_2S etc.) and transport, it is used for its methane content for different applications. While 27.0% of the industrial end energy consumption (sectors industry, trade and service) was covered by NG, only 0.3% of the transport fuels used were covered by NG in 2012 in Germany (DIW Berlin & EEFA Köln, 2014).

The number of cars using alternative fuels will grow within the next decades (Shell Deutschland Oil GmbH and Prognos AG, 2014). As Ridjan et al. (2016) stated, methane is part of a wide-range amount of alternative fuels. It is highly compressed at service stations (then called CNG for compressed natural gas) (Shell Deutschland Oil GmbH and Prognos AG, 2014). In Germany, NG use for transport is less taxed than petrol and diesel, it is commercially available, the technology is well-established and there is a rather close-meshed network of service stations.

Although the use of treated biogas for traffic is well studied (for example Tsvetkova et al. (2015)), the production and distribution of CO_2 based SNG is new. First installations produce SNG from biogas, where CO_2 is separated from raw biogas, compressed and methanated with H_2 (Waldstein, 2015). The production of H_2 via electrolysis is energy intensive and would lead to various greenhouse gas emissions if fossil energy carriers are used instead of renewables (BTS et al., 2014). Therefore, greater use of electrolysis is only sensible if renewable energy is used. Current concepts count on the growing availability of (surplus) wind energy. Although we choose wind as power source for electrolysis, numerous other sources of energy like photovoltaics are thinkable. A detailed life-cycle-assessment can be found in (Bhandari et al., 2014).

After methanation, SNG is ready to use. Especially the high purity of CO_2 and the already existing quantity of methane in raw biogas, together with the use of an existing infrastructure is an advantage for that route of SNG production. Using the existing NG pipeline system and the underground storages in Germany, methane transport and storage is easier to handle than transport of other chemicals such as H_2 or carbon monoxide (CO) (Walspurger et al., 2014).

Steam reforming (2) is the state-of-the-art in producing synthesis gas in Germany (Biedermann et al., 2006). Methane (CH_4) and the lighter fractions of crude oil are used as feed. We considered methane and water as starting materials in this endothermic synthesis:

$$CH_4 + H_2O \rightarrow CO + 3H_2 (+206 kJ/mol) \quad (2)$$

This process requires a large amount of heat and electricity (Linde, 2012). Synthesis gas is a key intermediate for a various number of other products as methanol. Its production from SNG is exemplified by Günther (2007).

Our analysis focusses on a comparison of the global warming potential (GWP_{100}) of NG with SNG and their use as raw material for the production of synthesis gas in chemical industry via steam reforming versus use as fuel for car mobility. In addition, the influence of the spatial distance between production and use of the SNG on the comparison will be analysed.

2. Methodology

2.1. General approach

We chose an attributional life-cycle-assessment (a-LCA) for this greenhouse gas balance. The data calculation is based on Ecoinvent's "cut-off" system model (Weidema et al., 2013) and was done with Nexus OpenLCA 1.4.1 (Ciroth et al., 2015).

2.2. Process chains of NG

NG production starts with resource extraction of crude NG in Russia, Norway, the Netherlands and Germany (Fig. 1). Drying (removal of water) and sweetening (removal of H_2S) follow, heavy hydrocarbons and other substances are removed from natural gas in the last steps of purification (Schori and Frischknecht, 2012). NG is compressed, fed into pipelines and transported to Germany. After its storage and transport in the German gas grid to the user, it can

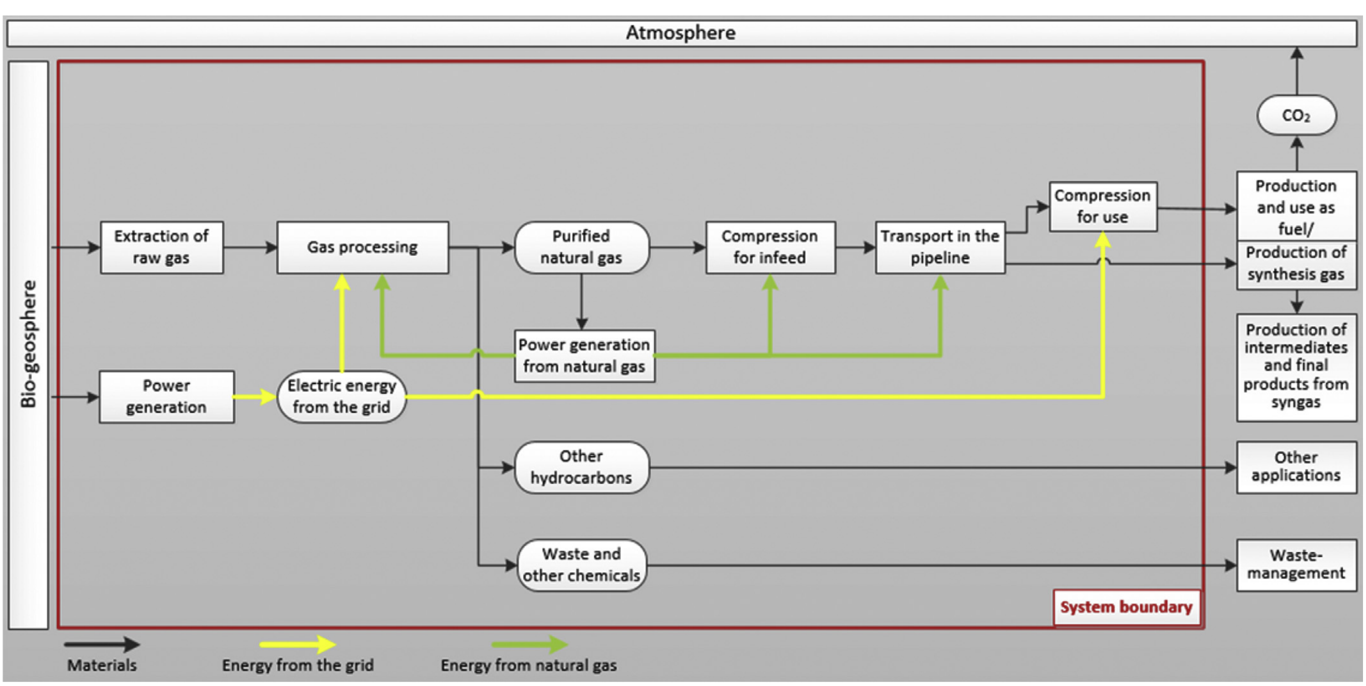

Fig. 1. Process chain of extraction, production and use of NG.