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LCA OF BIOMETHANE

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ABSTRACT

As a renewable substitute for natural gas in the pipeline system, biomethane is a key option on the way to sustainable, renewable energy supplies. This paper evaluates biomethane production from energy crops with respect to its environmental impact and energy efficiency, taking into consideration own measurements and experience data from a modern, commercial plant as well as current studies. According to this study the specific GHG emissions associated with the production of biomethane amount to as little as 43.9 g CO_2eq/kWh, corresponding to an overall GHG emission reduction of 82% compared with natural gas. The specific non-renewable energy demand of the entire process is very low at only 12%. These two indicators are due either to environmentally friendly plant cultivation (fermenter residues used as fertilizer) or to optimized plant design and operation (amine upgrading, renewable process heat, gas-tight equipment, industrial process control system).

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1. INTRODUCTION

As a renewable substitute for natural gas in the pipeline system, biomethane is a key option on the way to sustainable, renewable energy supplies. In this context, Germany faces considerable challenges if it is to achieve the political targets of 6 billion m³/year of biomethane in the gas system in 2020 and 9 billion m³/year in 2030. These targets can only be reached by using significant quantities of substrates consisting of energy crops (e.g. maize) and additional agricultural and commercial residues (manure and food residues).

As a leading gas supplier, E.ON Ruhrgas AG is directly involved in biomethane production and distribution. It currently operates 7 advanced biomethane plants using mainly energy crops as feedstock. While the main focus of technical development activities is on biomethane production and treatment as innovative technologies, environmental and energy efficiency assessment and optimization of the entire biomethane chain through to utilization is another key area (Fig. 1).

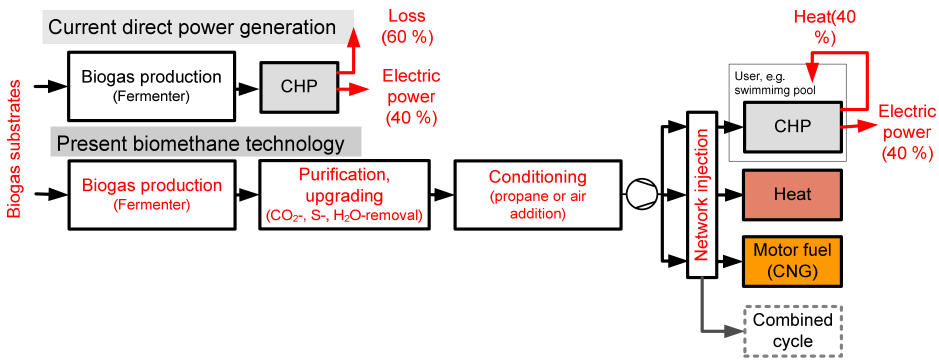


Fig. 1 Biomethane production and utilization chain

This paper evaluates biomethane production with respect to its environmental impact and energy efficiency, taking into consideration current analyses and own measurement data while also addressing some biological and agricultural topics.

The results are used for identifying and developing optimization potential within the entire production and utilization chain and thus for improving environmental efficiency and economic viability. They also help to position biomethane in current and future energy supply systems.

2. BIOMETHANE PLANT AS EXPERIENCE BASIS

The experience basis for this study is a modern biomethane plant in Einbeck/Germany, which is operated by E.ON Bioerdgas GmbH (Fig 2).

Fig. 2 Biomethane plant in Einbeck (courtesy of E.ON Bioerdgas GmbH)

The plant is run with a mix of energy crops with a high share of maize and seasonally varying shares of grass, sugar beet and millet. It is equipped with a comprehensive process control system recording data such as substrate input as well as gas and energy (heat and electricity) flows in all process stages to provide an overall continuous performance record. The analysis is based on a one-year operation period.

Additional measurements of diffuse methane losses over the entire plant were performed using proprietary infrared equipment for the methane leakage detection and subsequent flow rate measurements. They revealed very low methane emissions of only 0.1% of the output including the off-gas from the upgraded plant. For comparison, the corresponding values assumed in several recent studies including [1] vary between 0.5 and 1%.

The basic processes and system limits of the biomethane production plant in Einbeck were specified on the basis of the standards above (Fig. 3).

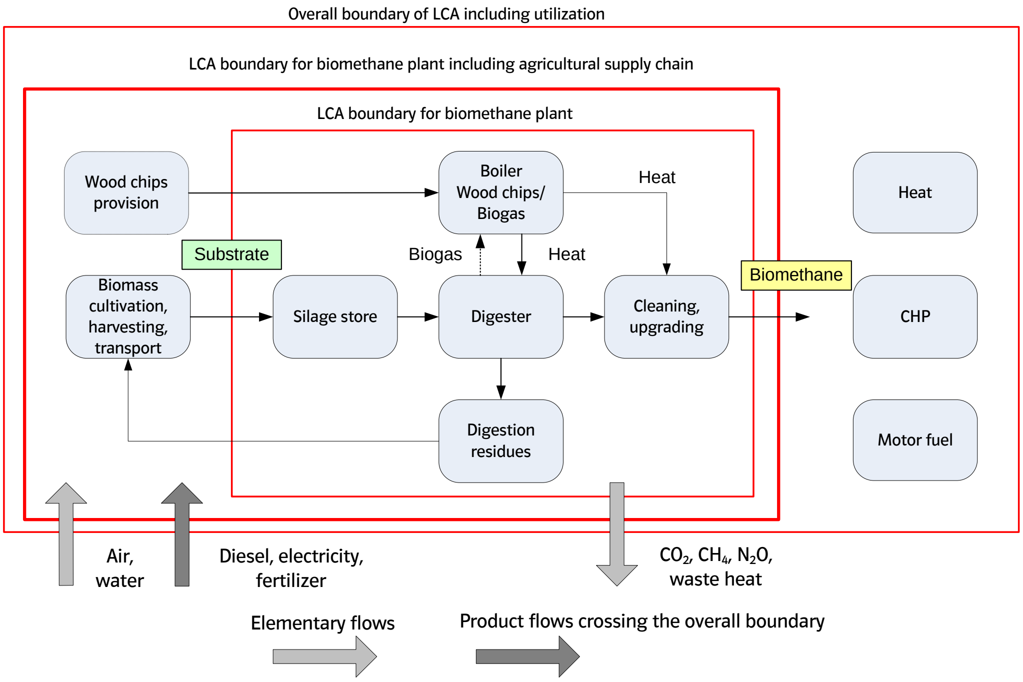


Fig. 3 Basic processes of the biomethane production plant in Einbeck

For ecological and economic reasons, process heat generation at this biomethane plant is based on two renewable sources - wood chips or biogas - allowing the operator to always select the cheaper fuel. Consequently, the plant is equipped with two separate boilers each designed for the entire heat demand of the digester and the amine regeneration unit. For this analysis the wood chip boiler was considered to be the dominating heat source. However, biogas boiler operation does not significantly alter the LCA results.

Biogas upgrading to biomethane with a methane content of over 96% is achieved by means of an amine gas treating process at a pressure which is only slightly above atmospheric. This process is characterized by low electricity demand and minor residual methane levels in the off-gas. For amine regeneration, renewable heat is supplied as described above.

The electricity required for plant operation is provided by the public grid. There is no generation unit on site.

3. APPLICATION OF LCA FOR BIOMETHANE

The methodology used for Life Cycle Assessments (LCA) is defined in the international standards [2] and [3] together with a number of more detailed guidelines and specialist reports.

Life cycle assessment is different from many other ecological assessment methods such as an environmental impact assessment because it adopts a relative approach based on a functional unit. In this case, by analogy with other energy generation systems, the **functional unit** is **1 MJ or 1 kWh biomethane (in terms of net calorific value)**.

By analogy with other fossil and renewable energy sources, the assessment of biomethane is based on the two most evident key **indicators:**

- **greenhouse gas emissions** (GHG, CO_2 equivalents) in g CO_2eq./MJ or g CO_2eq./kWh and
- **cumulative energy demand** (CED) in MJ/MJ or kWh/kWh.

Greenhouse gas emissions are expressed as GWP_{100} in accordance with IPCC (International Panel for Climate Change) guidelines and describe the contribution of emissions to the greenhouse effect over 100 years and thus also climate change. In the case of bio fuels, "CO_2 equivalents" refers to all of the emissions of the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which are converted using appropriate factors (IPCC 2007 factors). The objective of this study is to evaluate CO_2 equivalents of the biomethane production processes with a view to further optimizing and achieving significant reductions in greenhouse gas emissions compared with fossil fuels.

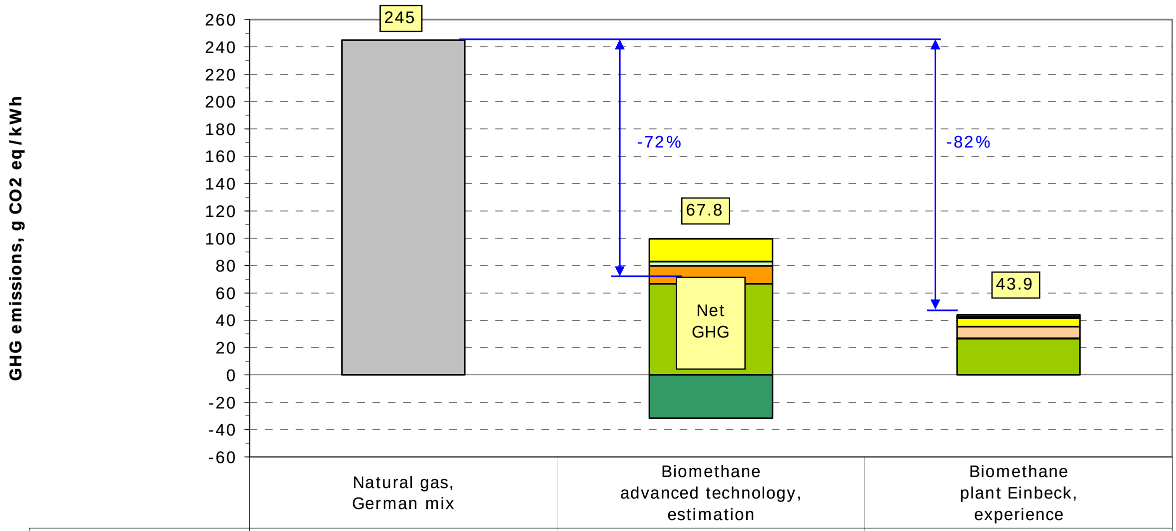
The cumulative energy demand (CED) per unit of final energy includes all the primary energy inputs along the production process including all sub processes [4]. Material inputs (fertilizers etc.) are quantified in terms of their own CED. The CED indicator describes the use of fossil or renewable energy sources and is a measure of energy efficiency.

4. GHG EMISSIONS OF BIOMETHANE

Greenhouse gas emissions associated with biomethane cover emissions from the entire production chain, i.e. substrate production, harvesting and transportation, fermentation, fermenting residue management, upgrading of biogas to natural gas quality and provision of energy for the biogas plant.

These processes are characterized by parameters relevant to greenhouse gas emissions, some of which are taken from agricultural and process engineering practice, including diesel and fertilizer use per hectare, while others are based on estimates such as nitrous oxide emissions and the properties of fermentation residue used as a fertilizer. These parameters are gradually improving with technological and scientific advances. In this study the evaluation of the specified biomethane plant was verified on the basis of comprehensive measurements and experience data showing significant improvements.

The greenhouse gas emissions for the various process stages as estimated for an ‘advanced technology plant’ and verified on an experience basis for the Einbeck plant (Fig. 4).



	Natural gas, German mix	Biomethane advanced technology, estimation	Biomethane plant Einbeck, experience
Residue fertilizer credit		-31,8	
CH4-emissions overall			1,40
Upgrading, heat			0,85
Upgrading, power		16,6	6,32
Residue management		3,2	
Fermenter, power			8,46
Fermenter, heat		13,2	0,25
Substrate production	245	66,6	26,57

Fig. 4 Greenhouse gas emissions for biomethane production, compared with natural gas

The "advanced technology" estimation [1] according to Fig. 4 has already revealed considerable improvements over the previous biomethane plant generation. These improvements include in particular a reduction of silage losses and diffuse methane emissions (gas-tight plants) and the more efficient use of fermentation residue as fertilizer. This estimation was performed for Pressure Swing Adsorption (PSA) as the upgrading technology.

As expected, substrate production including maize cultivation, harvesting and transport as well as silage storage accounts for the largest share in greenhouse gas emissions. Cultivation is also associated with nitrous oxide emissions which are another significant source of greenhouse gases. In accordance with the IPCC requirements, these emissions are assessed at 1% of the N fertilizer applied.

The most important measure which can be taken to reduce greenhouse gas emissions in substrate production is to use fermentation residues as a fertilizer, allowing the replacement of K and P fertilizers in their entirety as well as 60 % of the N fertilizer, which is associated with the highest greenhouse gas emissions. The resulting credit reduces overall emissions by up to 32 g CO_2eq/kWh and contributes significantly to the overall cut in GHG emissions by 72 % compared with natural gas (German mixture) for an "advanced technology" plant.

The evaluation of own measurements and experience data as a basis of this study revealed specific GHG emissions of as low as 43.9 g CO_2eq/kWh and an overall GHG emission reduction of 82% compared to natural gas, as shown for the Einbeck plant (Fig. 4). In this approach the GHG emissions associated with substrate provision were calculated directly, i.e. without credits, as the experience data for the energy crops production were used. For this evaluation some supplementary agricultural data were taken from [5].

As far as nitrous oxide emissions are considered 0.6% of the overall N fertilizer applied was assumed in accordance with [6] as an average value for Germany. However, also this figure seems to be too conservative and is attributed to background emissions as a late effect of the over-fertilization in the past. It is anticipated that on farmland without over-fertilization effect these emissions do not occur.

In addition to the main optimization measures (minimised silage losses, gas-tight equipment and fermentation residue-based fertilizer) listed above, a new upgrading technology involving amine gas treating was applied. Unlike PSA upgrading, amine gas treating does not require gas compression, which significantly reduces electricity consumption. Moreover, the heat needed for amine regeneration is provided by a renewable source (wood chips) and the treated off-gas contains only very little methane so that upgrading as a whole has very low GHG emissions.

While the potential to further reduce GHG emissions by improving substrate provision or modifying technical equipment is largely exhausted, on-site generation of renewable power and heat (CHP) or "green electricity" are options that should at least be looked at in terms of their cost-benefit performance.

It is worth pointing out that in addition to producing biomethane from energy crops (as considered in this paper), the use of agricultural residue substrates such as manure or bio waste can help avoid up to 97% of GHG emissions. However, these substrates have limited potential and their availability is restricted.

5. CUMULATIVE ENERGY DEMAND OF BIOMETHANE

To allow the energy efficiency of a biomethane plant to be assessed, all energy and raw material flows are expressed in terms of primary energy and shown in Sankey diagrams. A diagram for a biomethane plant with renewable heat generation by a wood chip boiler is shown in Fig. 5.

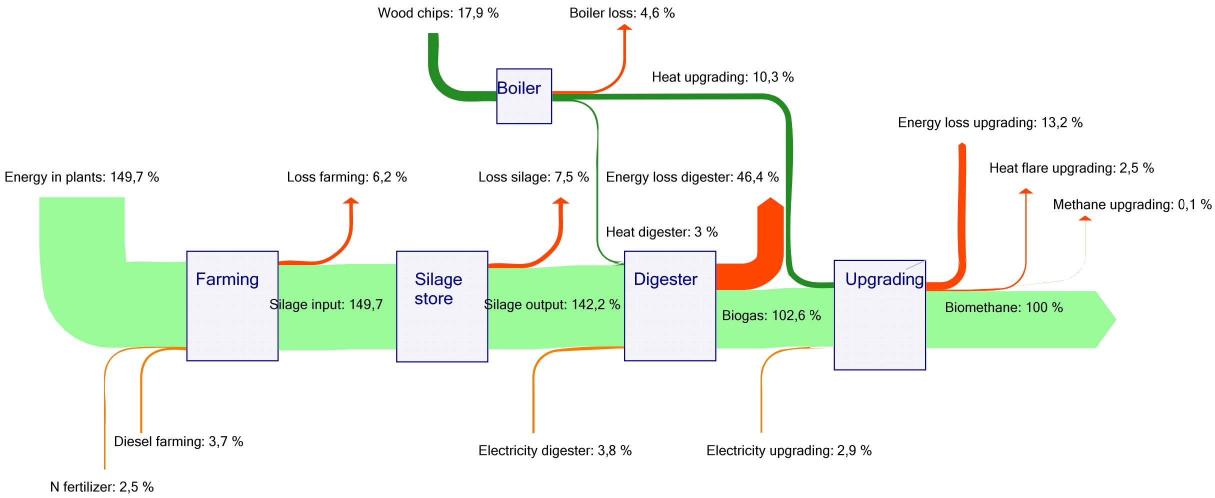


Fig. 5 Energy flow diagram (Sankey diagram) for the biomethane plant in Einbeck

The evaluation is based on the low (LHV) or high (HHV) heating value of all energy and material inputs (as primary energy equivalent, e.g. for fertilizer) in accordance with the CED definition and its graphic interpretation. However, this approach leads to an apparently lower efficiency of the biological processes because the heating value can only be utilized in combustion processes. The maximum energy yield from a biological process, however, corresponds to the total amount of methane which can be produced from a substrate by bacteria. This parameter is more relevant for low-temperature anaerobic processes as described here. While the digester efficiency on an LHV basis (see Fig. 5) amounts to approx. 70%, the biological efficiency reaches approx. 80%, which corresponds to the digestible energy share of the silage. Only non-digestible lignocellulose remains in the digester residue and is transported back to the farmland.

Aside from the total CED of biomethane production of 180.4% in the plant under consideration, the non-renewable part (CED_{NR}) is an important indicator characterizing the fossil inputs. In this case, the electricity required is taken from the public grid with a current fossil/renewable ratio in Germany of 88%/12%. Other fossil inputs are N-fertilizer and diesel for farming and transport. Because of the optimization measures in crop cultivation and biomethane plant design and operation mentioned above, the overall non-renewable cumulative energy demand (CED_{NR}) is very low value at 12%. This indicator, also known as the primary energy factor, represents the fossil energy consumed per unit of final energy produced and should gradually decrease as the sustainable economy develops. As already mentioned in chapter 4, on-site generation of renewable electricity and heat (CHP) or "green electricity" under contract could help reduce GHG emissions and non-renewable energy input at the same time.

6. CONCLUSIONS

Biomethane is currently the most important renewable option for gas supplies and is fully compatible with natural gas. With the construction of advanced plants and continuous improvements in crop cultivation and plant operation, a reduction in greenhouse gas emissions of more than 80 % compared with natural gas appears feasible based on the experience outlined in this paper.

The most effective ways of achieving low GHG emissions and high process performance in terms of energy demand and costs are:

- utilization of fermenter residues as fertilizer;
- minimisation of silage losses by appropriate silage storage;
- use of highly efficient upgrading technologies requiring little electricity with low methane losses in the off-gas;
- use of gas-tight equipment and monitoring of diffuse methane losses.

Using residue substrates such as manure or bio waste instead of energy crops can help avoid up to 97% of GHG emissions. However, these substrates are limited in their potential and regional availability.

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