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**PRODUCTION OF BIO METHANE
FROM WOOD
USING THE MILENA GASIFICATION TECHNOLOGY**

Christiaan van der Meijden

Luc Rabou

Britta van Boven (Gasunie)

Bram van der Drift

Mark Overwijk

ECN

The Netherlands

ABSTRACT

An increasing number of countries are setting strict targets to replace part of their fossil natural gas consumption by bio-methane in an effort to reduce CO₂ emissions. The production of bio-methane through digestion is fully developed and is currently implemented on relatively small production scales. The limited amount of suitable digestible feedstock calls for development of a technology which can convert a wider range of readily available feedstock, like (waste) wood and forest residue, into bio-methane. Gasification is such a technology.

Bio-fuels like bio-methane produced from biomass have the potential to become a CO₂-negative fuel. Part of the carbon from biomass is transformed into CO₂ during the production process, and when this pure CO₂ stream is sequestered, these fuels become truly CO₂ negative. This could be an attractive option for even reducing the level of greenhouse gases in the atmosphere.

Several bio-methane demonstration projects are underway based on gasification of woody biomass. Most of these projects are planning to produce bio-methane for transportation purposes. Bio-methane for Natural Gas Vehicles can very well compete with expensive bio-fuels like bio-diesel.

ECN produced the first bio-methane based on biomass gasification in 2004. An 800 kW_{th} pilot plant consisting of MILENA and OLGA was constructed in 2008. An extensive test program using demolition wood as fuel was done using the ECN pilot plant in 2010 and 2012. At the same time extensive lab-scale tests were done with different methanation catalysts and different process configurations. Results of these tests were positive and convinced the project partners of the technical feasibility of the concept.

In the last few years a lot of work has been done to prepare a demonstration plant. A consortium with a number of partners (Gasunie, HVC, Royal Dahlman) was formed to determine the feasibility of such a plant. On top of this, a subsidy application was made to make the demonstration economically feasible. A 23 million Euro subsidy was granted recently. It is expected that the final investment decision will be taken this year (2014). The size of the demonstration plant will be approximately 0.003 bcm of natural gas per year. The produced bio-methane will be injected in the gas grid. The scale foreseen for a commercial single-train bio-methane production facility is between 0.03 and 0.3 bcm/year.

1. INTRODUCTION

Energy is one of the essential ingredients of modern society. Nowadays energy comes mostly from fossil fuels like oil, natural gas and coal. The proven fossil fuel reserves are declining in most parts of the world. This demands for the development of sustainable alternative energy sources.

On top of the problem of securing the supply, the combustion of fossil fuels produces CO₂, which contributes to global warming. CO₂ emissions from fossil fuels can, to some extent, be counteracted by sequestration of CO₂. This CO₂ sequestration, however, lowers overall efficiency significantly, resulting in a higher consumption of fossil fuels per unit of energy delivered and consequently a faster decline of fossil fuels reserves.

Sustainable alternatives like wind, solar or biomass energy are required to replace the declining production of fossil fuels without increasing the amount of CO₂ in the atmosphere. Energy from biomass is a good addition to wind and solar energy, because of its continuous availability whereas wind energy and solar energy are intermittent energy sources. Also biomass is the only renewable carbon source for the production of fuels, chemicals and materials.

Natural gas plays an important role as an energy source worldwide. Natural gas is a relatively clean primary energy carrier and is therefore often the fuel of choice in many regions of the world.

Replacing part of natural gas by Bio-Methane, produced from a sustainable primary energy source, with the same properties as natural gas facilitates the implementation of sustainable energy since natural gas grids are widespread in many countries. A Substitute Natural Gas can be produced from biomass (Bio-SNG or Bio-Methane) with a high efficiency and with low emissions from the plant itself (comparable with modern power plants).

Biomass transport can be limited by locating the Bio-Methane production facility where the biomass is collected, but this limits the size of the installation. Large scale installations would benefit from a location next to harbors.

- **CO₂ balance of Bio-SNG**

Biomass is considered a CO₂ neutral fuel, because the amount of CO₂ released on burning biomass equals the amount taken from the atmosphere during growth of the biomass. Fuels like hydrogen, methane, Fischer Tropsch (FT) diesel and methanol produced from biomass have the potential to become a CO₂ negative fuel, because part of the biomass carbon is separated as CO₂ during the production process and can be sequestered. This might be an attractive option for reducing the level of greenhouse gases in the atmosphere.

Figure 1 shows an indicative overall CO₂ balance, including emissions from harvesting and transport, for a Bio-Methane production facility based on gasification as described in this paper.

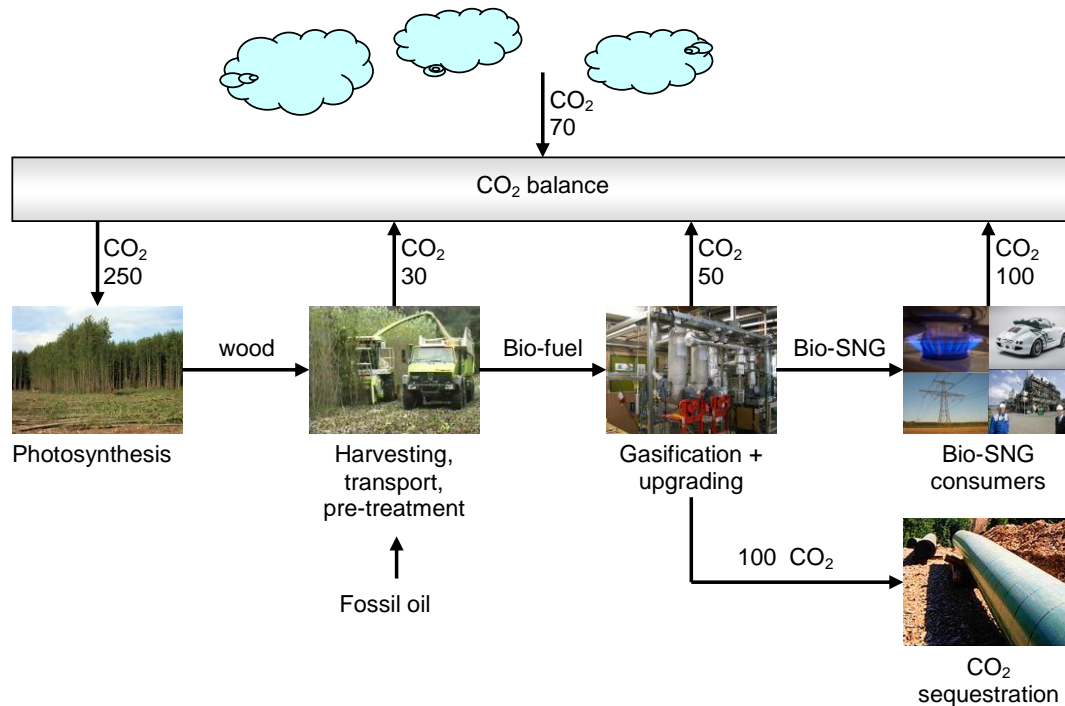


Figure 1: Indicative CO₂ balance for Bio-SNG system based on MILENA gasification.

If the pure CO₂ stream that is available from the Bio-Methane production process is not vented into the atmosphere but sequestered in an empty gas field or used for Enhanced Oil Recovery (EOR), the net CO₂ emissions become negative (-70% or a reduction of 170% compared to using conventional natural gas). Without CO₂ sequestration the CO₂ reduction of Bio-Methane is approximately 70% compared to natural gas.

- **Bio-Methane production pathways**

There are two main options to produce Bio-Methane from biomass:

1. Anaerobic digestion (biological conversion at low temperature).
2. Gasification (thermo chemical conversion at high temperature).

Anaerobic digestion is a process carried out by bacteria. The bacteria grow by converting organic matter into biogas (mainly CH₄ and CO₂). Biogas production is a proven technology. In 2007 more than 3500 anaerobic digesters were in operation in Germany [1].

Most of the present biogas production comes from landfills and waste water treatment plants. The biogas production from landfills is in decline, due to the ban on depositing organic material, whereas the number of dedicated co-digestion plants using manure and food wastes is increasing. Biogas can be used in a gas engine for electricity and heat production but can also be upgraded to natural gas grid quality by removal of CO₂, gas cleaning (sulfur removal) and compression. Biogas plant are typically relatively small, because of the local availability of the (wet) feedstock.

Gasification of biomass is less limited by biomass supply compared to digestion, because a wider range of biomass fuels are suitable to be used as feedstock and the amounts available are larger. Bio-Methane production by digestion and gasification are not competing processes, because the types of feedstocks are different.

Production of Bio-Methane via gasification offers the opportunity to mix in hydrogen produced from an excess of renewable electricity. H_2 reacts with the excess of CO_2 into CH_4 and H_2O . This is the so called “power to gas” concept.

The Energy research Centre of the Netherlands (ECN) decided almost ten years ago that the production of Bio-Methane by gasification is an attractive option to develop and started the development of the MILENA gasification technology that is optimized for large scale production of Bio-Methane from (woody) biomass.

2. BIO-METHANE PRODUCTION BY GASIFICATION

Figure 2 shows the process layout for the production of Bio-Methane from biomass by gasification.

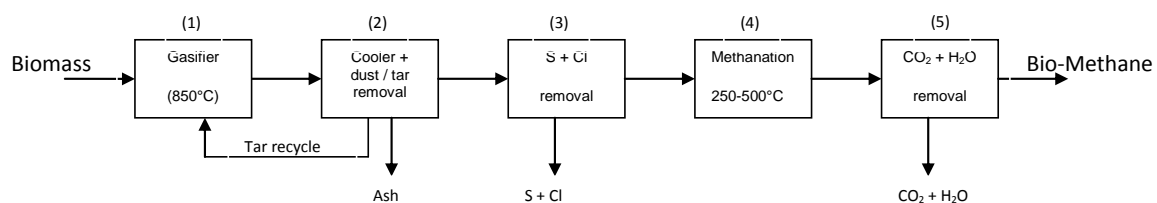


Figure 2: simplified process scheme for production of Bio-Methane by gasification.

The overall Bio-Methane production process uses the following production steps:

- 1) A gasifier where solid biomass is converted into a producer gas.
- 2) Gas cooling and tar removal.
- 3) Gas cleaning where the pollutants are removed from the producer gas.
- 4) Catalytic conversion of producer gas into CH_4 , CO_2 and H_2O .
- 5) An upgrading step where water and CO_2 are removed and the CH_4 is compressed.

In the gasifier the solid biomass (e.g. wood) is converted, at high temperature, into a combustible gas containing mainly CO , CO_2 , H_2 , H_2O , CH_4 , C_2H_4 and C_6H_6 , but also pollutants like dust (ash), tar, chloride, sulfur, etc. After cooling of the gas tars and dust are removed in the primary gas cleaning. Sulfur and chlorides are removed to below ppm level to protect the catalysts used for the methanation. Methanation of the gas is usually done in catalytic reactors using nickel catalysts. The cleaned gas is converted into a mixture of CH_4 (and possibly C_2H_6), H_2O and CO_2 . After removal of CO_2 and H_2O and compression of the gas to the desired pressure, the gas can be injected in the gas grid or can be converted to LNG.

3. BIOMASS GASIFICATION

The term gasification is applied to processes which convert solid or liquid fuels into a combustible gas at high temperature. The heat required for the heating of the fuel and to energize the endothermic gasification reactions is supplied by the combustion of part of the fuel (Direct gasification) or is supplied from an external source (Indirect or Allothermal gasification).

For the production of Bio-Methane a producer gas with a low nitrogen content (< 2 vol%) is required, because the nitrogen ends up in the Bio-Methane. All commercial BFB and CFB biomass gasifiers use air as gasification agent. This results in a producer gas containing approximately 50 vol% of nitrogen. Dilution of the producer gas with nitrogen can be prevented by replacing the gasification air with a mixture of steam and oxygen. Oxygen can be produced by an Air Separation Unit (ASU), but investment cost and energy consumption are relatively high. Experience with oxygen steam blown fluidized bed gasification is limited, no commercial size units are in operation at the moment. Indirect gasifiers produce a gas that contains no or very limited amount of nitrogen, because no air is added to the gasification process.

ECN selected indirect gasification as the most promising technology for the production of Bio-Methane [2] and constructed a lab-scale installation in 2004. The technology is named MILENA.

4. MILENA GASIFICATION TECHNOLOGY

The MILENA gasifier [3] contains separate sections for gasification and combustion. Figure 3 shows a simplified scheme of the MILENA process. The gasification section consists of three parts: riser, settling chamber and downcomer. The combustion section contains two parts, the bubbling fluidized bed combustor and the sand transport zone. The arrows in Figure 3 represent the circulating bed material. The processes in the gasification section will be explained first.

Biomass (e.g. wood) is fed into the riser. A small amount of superheated steam (or any other gas available including air) is added from below to enable bed material circulation in the bottom of the riser reactor. Hot bed material (typically 925°C sand or olivine of 0.2-0.3 mm) enters the riser from the combustor through a hole in the riser. The bed material heats the biomass to 850°C. The heated biomass particles degasify; they are converted into gas, tar and char. The volume created by the gas from the biomass results in a vertical velocity of approximately 6-7 m/s, creating a “turbulent fluidization” regime in the riser and carrying over of the bed material together with the degasified biomass particles (char). The vertical velocity of the gas is reduced in the settling chamber, causing the larger solids (bed material and char) to separate from the gas and fall down into the downcomer. The producer gas leaves the reactor from the top and is sent to the cooling and gas cleaning section.

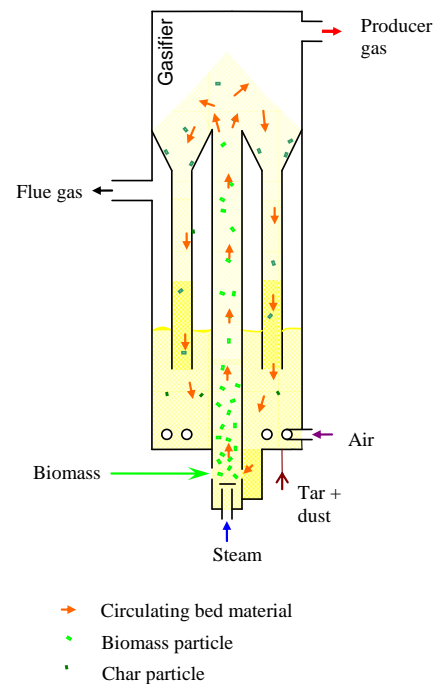


Figure 3: Simplified scheme of MILENA

The combustor operates as a bubbling fluidized bed (BFB). The downcomer transports bed material and char from the gasification section into the combustor. Tar and dust, separated from the producer gas, are also returned to the combustor. Char, tar and dust are burned with air to heat the bed material to approximately 925°C. Flue gas leaves the reactor to be cooled, de-dusted and emitted. The heated bed material leaves the bottom of the combustor through a hole into the riser. No additional heat input is required; all heat required for the gasification process is produced by the combustion of the char, tar and dust in the combustor.

The flue gas leaving the MILENA installation is cooled down to approximately 100°C and is cleaned in a bag house filter. If clean wood is used as a fuel no additional flue gas cleaning is required.

The hot producer gas from the gasifier contains several contaminants such as dust, tar, chloride and sulfur, which have to be removed before the catalytic conversion of the gas into Bio-Methane. The producer gas is cooled and tar and dust are removed from the gas in the OLGA gas cleaning section [4]. The OLGA gas cleaning technology is based on scrubbing with liquid oil. Dust and tar removed from the producer gas are sent to the combustor of the MILENA gasifier. The cleaned producer gas contains mainly CO, CO₂, H₂, CH₄, C₂H₄ and C₆H₆. After removal of sulfur and chloride this gas can be converted into methane using commercial catalysts.

5. The ECN BIO-METHANE PRODUCTION CONFIGURATION

ECN selected the process layout as shown in Figure 4. The MILENA gasifier and OLGA tar removal unit are operated near atmospheric pressure. After tar removal water is removed from the gas, because this is required for the compressor. The removal of water is undesired because water is required later on in the process. The gas pressure is increased to a few bar. It is expected that the operating pressure of the MILENA gasification technology will be increased to a few bar, so the gas does not need to be compressed anymore and the water can stay in the gas.

A Hydro-DeSulfurization (HDS) catalyst is used to convert organic sulfur compounds (thiophenes) into H₂S, because the removal of organic sulfur compounds is not possible with the foreseen sulfur removal technologies to a sufficiently low level (<< 1 ppm). The HDS reactor is operated above 300°C, so the gas needs to be heated before the catalysts and is cooled again after the HDS unit. Many different technologies are available for the removal of H₂S (and COS). ECN uses ZnO in their lab-scale installations. ZnO will be used as a guard bed after a bulk sulfur removal technology in the demonstration installation. After sulfur removal a pre-methanation or pre-reforming step is foreseen. In this catalytic reactor the higher hydrocarbons (e.g. benzene and toluene) are reformed and some of the syngas is converted into methane. The typical operating temperature of the pre-reformer is between 550°C and 600°C. The reforming reactions are endothermic, but the methanation reactions are exothermic, this makes the overall reaction adiabatic or slightly exothermic. Before the pre-reformer the gas needs to be heated and after the heat exchanger cooling is required. Some steam is added to the gas to prevent the formation of soot on the catalyst surface. The need for heat exchangers for the HDS and Pre-reforming reactors is one of the disadvantages of this system layout.

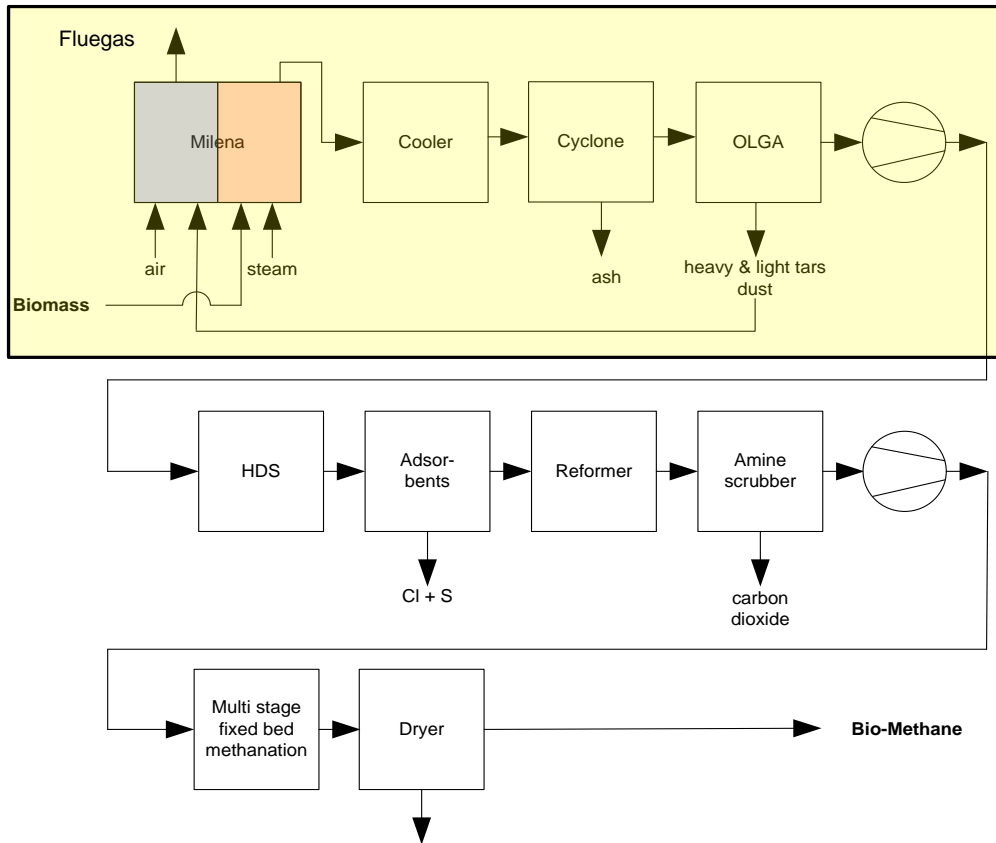


Figure 4: Bio-Methane system lay-out.

After the conversion of the higher hydrocarbons a conventional amine scrubbing system can be used to remove approximately 85% of the CO₂ from the gas. After CO₂ and water removal the remaining gas is compressed to the typical operating pressure of commercial methanation catalysts. The methanation reactors are normally placed in series with cooling in between. A gas recycle might be used to limit the temperature in the reactor. The CO₂ removal is tuned in such a way that the remaining CO₂ reacts with the surplus of H₂ in the gas to CH₄ and H₂O. After removal of the produced water the gas is ready for gas grid injection.

ECN has been working on catalytic conversion of producer gas since 2004. In recent years several duration tests were carried out to find optimum process conditions and to increase the lifespan of the different catalysts. Only commercially available catalysts are used in the process. All catalytic conversions are performed using adiabatic fixed bed reactors, this makes scaling up the process easy. The results from the different duration tests show that the lifespan of the catalyst is sufficient for commercial application. ECN is continuing the tests to further reduce catalyst consumption and to optimize the process economics. The real test for the catalysts will be the foreseen demonstration plant that will run continuously.

6. MILENA BIO-METHANE DEMONSTRATION PROJECT

The Bio-Methane demonstration plant will be built by a consortium consisting of Gasunie, ECN, Dahlman and several other parties interested in Bio-Methane. Waste company HVC was strongly involved in the preparations for this project.

Preparations for this project have been ongoing for several years. The configuration and scale have been modified several times because of changes in Dutch subsidy schemes and in the consortium partners. Recently, a subsidy of 23 million euro on the sales of the produced Bio-Methane was granted for a period of 12 years. The final investment decision by the different partners is expected before the end of 2014. Start of construction is expected in 2015.

The demonstration plant will be part of The Netherlands Expertise Centre for Biomass Gasification in Alkmaar and will include facilities to test new conversion technologies. The capacity of the plant will be 4 MW_{th} biomass input. Expected output of Bio-Methane is 0.003 bcm/year.

The next step will be a commercial plant of approximately 0.03 bcm/year. The scale foreseen for a commercial single-train Bio-Methane production facility is between 50 and 500 MW_{th} which corresponds with 0.03 – 0.3 bcm/year.

7. ECONOMICS

Although bio-methane is a good option from an environmental point-of-view, it must to be compared with sustainable alternatives on cost to assess its economic perspective. A study was carried out by ECN in 2014 to determine the expected production cost for Bio-Methane produced by biomass gasification at large scale [5]. Figure 5 shows the calculated production cost for two different cases.

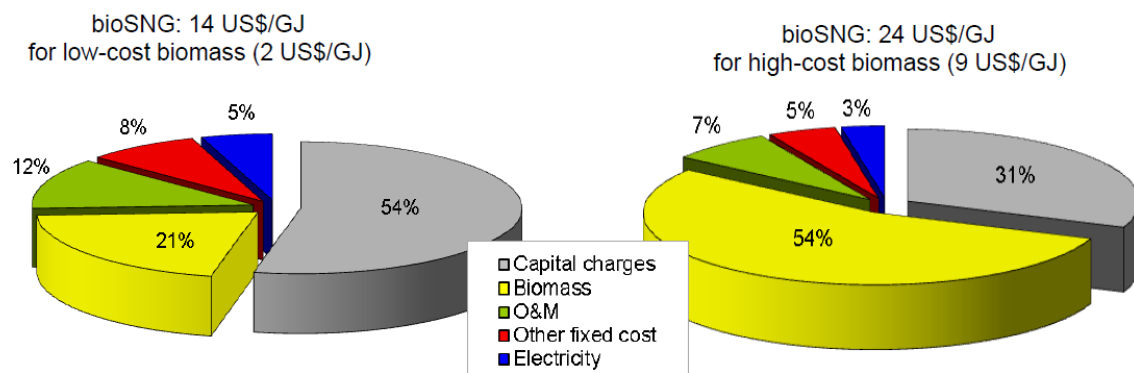


Figure 5: Bio-Methane production costs based on biomass gasification

Production cost for large-scale Bio-Methane production is to a significant extent determined by the cost of the biomass used as feedstock. Accordingly, the technology with the highest overall efficiency and that can handle low-cost biomass fuels like demolition wood is preferred.

Bio-Methane cannot compete on price with natural gas, but this is true for all sustainable alternatives. Bio-Methane is expected to be able to compete with the other bio-fuels like Bio-Diesel and Bio-Ethanol. The calculated production cost of bio-methane for low-cost biomass is 14 USD/GJ and for high-cost biomass 24 USD/GJ. The IEA expects long term production cost for biofuels in the range of USD 0.65-0.90 / liter gasoline equivalent (approximately 30 – 42 USD/GJ) [6], so the proposed Bio-methane configuration based on gasification can easily compete even for the high-cost biomass case.

8. CONCLUSIONS

Production of Bio-Methane by gasification of woody biomass is an attractive option to replace fossil fuels and reduce CO₂ emissions. In combination with CO₂ sequestration, net CO₂ emissions can even become negative.

Bio-Methane is a good addition to other sources of renewable energy like wind and solar energy, because of its continuous availability, whereas wind energy and solar energy are intermitting forms of energy. Bio-Methane can easily be stored and used for additional electricity production when the other renewable sources are not available. Furthermore, hydrogen produced from excess renewable electricity can easily be converted into Bio-Methane when it is mixed with the producer gas prior to methanisation (power to gas concept).

Bio-Methane can be used in the transport sector in the form of CNG or LNG. The price of Bio-Methane is higher than that of natural gas, but it is expected to be competitive with other bio-fuels like Bio-Diesel and Bio-Ethanol.

Overall efficiency from wood to Bio-Methane can be as high as 70% (LHV basis) when the MILENA technology is used to gasify the biomass.

Different duration tests of the catalysts used to convert the producer gas into CH₄ have shown that the lifespan of the catalyst is sufficient to use them in the foreseen demonstration plant.

The optimization of the Bio-Methane production technology by gasification is ongoing. Lab-scale and pilot-scale testing have been performed. A demonstration project in Alkmaar (the Netherlands) on a scale of 4 MW_{th} (approximately 0.003 bcm/year) is under development. Recently a subsidy of 23 million euro for the produced Bio-Methane has been granted. The final investment decision by the different partners is expected to be taken before the end of 2014. Expected start of construction is 2015.

9. ACKNOWLEDGEMENT

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10. REFERENCES

1. Beurskens, L.W.M., Mozaffarian, M., Lescot, D., Tuille, F.F.G., 2009. [The State of Renewable Energies in Europe](#), Petten, The Netherlands, ECN, ECN-O--09-011.
2. van der Meijden, C.M., Veringa, H.J., Rabou, L.P.L., 2009. [The production of synthetic natural gas \(SNG\): A comparison of three wood gasification systems for energy balance and overall efficiency](#). Biomass & Bioenergy 34.
3. van der Meijden, C.M., 2010. [Development of the MILENA gasification technology for the production of Bio-SNG](#). Thesis, TU Eindhoven.
4. Boerrigter, H., van Paasen, S.V.B., Bergman, P.C.A., Könemann, J.W., Emmen, R., Wijnands, A., 2005. [OLGA tar removal technology](#), Petten, The Netherlands, ECN, ECN-C--05-009.
5. Aranda Almansa, G.; Drift, A. van der; Smit, R., 2014. [The Economy of Large Scale Biomass to Synthetic Natural Gas \(bioSNG\) plants](#), ECN, Petten, The Netherlands, ECN-E--14-008.
6. IEA., 2013. [IEA presentiaion - Biofuels & Bioenergy Technology Roadmaps 2013](#).