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**LARGE SCALE PRODUCTION OF BIO-METHANE  
FROM WOODY BIOMASS**

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## ABSTRACT

An increasing number of countries is setting objectives and obligations to replace part of their fossil natural gas consumptions by bio-methane to reduce CO<sub>2</sub> emissions. The production of bio-methane via digestion has been developed and is implemented on a small scale. The limited amount of suitable digestible feedstock demands for development of a technology which can convert a wider range of biomass fuels, such as wood into bio-methane. Gasification is such a route.

Gasification technology offers the possibility to convert lignocellulosic biomass (e.g. residual wood) into a combustible gas. This gas can be converted into natural gas quality gas (bio-methane) by catalytic processes.

Bio-fuels such as bio-methane produced from biomass have the potential to become a CO<sub>2</sub> negative fuel, because part of the biomass carbon is separated as CO<sub>2</sub> during the production process. If this pure CO<sub>2</sub> stream is sequestered, these bio-fuels become even CO<sub>2</sub> negative. This might be an attractive option for reducing the level of greenhouse gases in the atmosphere.

Several bio-methane demonstration projects are underway based on thermal gasification of woody biomass. The most well known is the 20 MW<sub>th</sub> GoBiGas project in Gothenburg by Göteborg Energi and E.ON.

ECN (Energy research Centre of the Netherlands) has developed an alternative gasification process (MILENA), optimized for the production of bio-methane. This system has an overall efficiency of 70% from wood to bio-methane. The technology is demonstrated at lab scale (30 kW<sub>th</sub>) and pilot scale (800 kW<sub>th</sub>). A 12 MW<sub>th</sub> demonstration plant is under preparation in close cooperation with the HVC Group who plan to act as launching customer.

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# 1. INTRODUCTION

Energy is one of the essential ingredients of modern society. Nowadays energy comes for the greater part 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 CO<sub>2</sub>, which contributes to global warming. CO<sub>2</sub> emissions from fossil fuels can, to some extent, be countered by sequestration of CO<sub>2</sub>. This CO<sub>2</sub> 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 CO<sub>2</sub> 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.

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.

- **The use of biomass for energy production**

Biomass energy is expected to make a major contribution to the replacement of fossil fuels. Worldwide primary energy consumption was 12.000 million tonnes oil equivalent in 2010 [1]. This corresponds to approximately 500 EJ per year. The future world-wide available amount of biomass for energy is estimated to be 200 to 500 EJ per year, based on an evaluation of biomass availability studies [2].

Biomass for the production of energy is controversial for several reasons. Corn is used on a large scale to produce ethanol to replace fossil gasoline. Palm oil is used to produce biodiesel. This resulted in the fuel versus food discussion. Large areas of rainforest have been cut down in Malaysia to create space for palm oil production. On top of this, some production processes for Bio-fuels require a large (fossil) energy input for logistic reasons and to upgrade the fuel to an acceptable quality. A well know example is the distillation of the water ethanol mixture to produce fuel quality ethanol. Some fast growing biomasses require nitrogen fertilizers, which are normally produced from natural gas. This has a negative effect on the overall CO<sub>2</sub> balance of the Bio-fuel. To deal with these issues Sustainability Criteria were introduced. These criteria include issues like the greenhouse gas balance, competition with food, biodiversity and local environmental issues. Woody biomass performs very well on these criteria, especially when the wood is converted into a low carbon fuel like methane.

- **CO<sub>2</sub> balance of Bio-SNG**

Biomass is considered a CO<sub>2</sub> neutral fuel, because the amount of CO<sub>2</sub> 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 CO<sub>2</sub> negative fuel, because part of the biomass carbon is separated as CO<sub>2</sub> 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 CO<sub>2</sub> balance, including emissions from harvesting and transport, for a Bio-Methane production facility based on gasification as described in this paper.

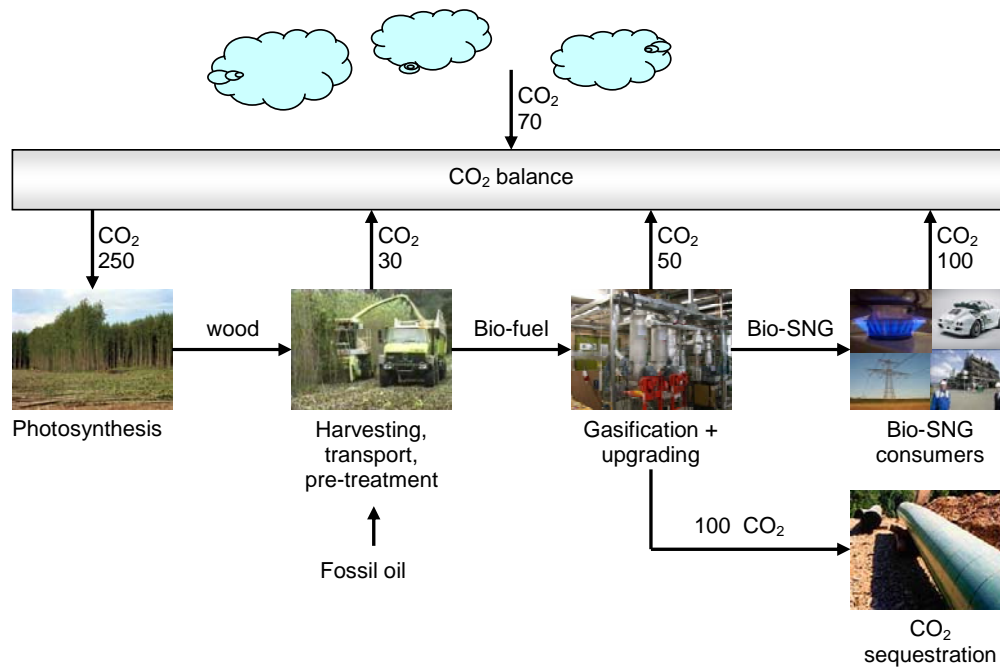


Figure 1: Indicative CO<sub>2</sub> balance for Bio-SNG system based on MILENA gasification.

If the pure CO<sub>2</sub> 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 CO<sub>2</sub> emissions become negative (-70% or a reduction of 170% compared to using conventional natural gas). Without CO<sub>2</sub> sequestration the CO<sub>2</sub> 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  $\text{CH}_4$  and  $\text{CO}_2$ ). Biogas production is a proven technology. In 2007 more than 3500 anaerobic digesters were in operation in Germany [3].

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  $\text{CO}_2$ , gas cleaning (sulfur removal) and compression. Biogas plant are normally 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 type of feedstocks are different.

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

- **The process**

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

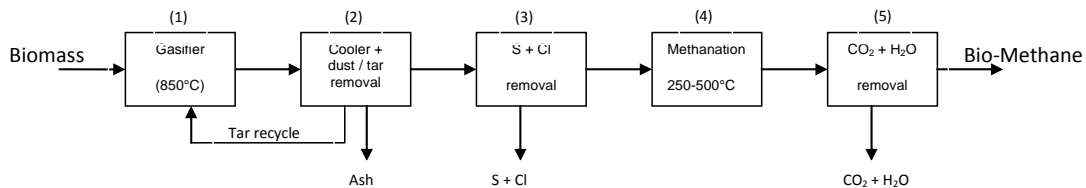


Figure 2: simplified process scheme for production of Bio-Methane by gasification.

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  $\text{CH}_4$ ,  $\text{CO}_2$  and  $\text{H}_2\text{O}$ .
- 5) An upgrading step where water and  $\text{CO}_2$  are removed and the gas is compressed.

In the gasifier the solid biomass (e.g. wood) is converted, at high temperature, into a combustible gas containing mainly  $\text{CO}$ ,  $\text{CO}_2$ ,  $\text{H}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{CH}_4$ ,  $\text{C}_2\text{H}_4$  and  $\text{C}_6\text{H}_6$ , 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<sub>4</sub> (and possibly C<sub>2</sub>H<sub>6</sub>), H<sub>2</sub>O and CO<sub>2</sub>. After removal of CO<sub>2</sub> and H<sub>2</sub>O 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).

- **Types of gasifiers**

Gasifiers can be divided into high temperature gasifiers (typical 1300 – 1500°C) which produce a syngas and medium temperature gasifiers (typical 850°C) which produce a producer gas. Syngas contains almost no hydrocarbons like methane. Entrained Flow gasifiers are the most common example of high temperature gasifiers. Entrained Flow gasifiers are developed to produce syngas from coal and oil residues. Gas coming from medium temperature gasifiers contains on energy basis up to 50% of hydrocarbons (mainly CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub> and C<sub>6</sub>H<sub>6</sub>). The producer gas from medium temperature gasifiers also contains some tars. Tars are heavy hydrocarbons, which can cause fouling problems when the gas is cooled. Producer gas also contains several other pollutants like H<sub>2</sub>S, COS, thiophenes, NH<sub>3</sub>, HCl, HCN and dust which need to be removed before application of the gas.

For processes like the synthesis of Fischer Tropsch Diesel or methanol the presence of large quantities of hydrocarbons is unwanted, because only CO and H<sub>2</sub> (and probably C<sub>2</sub>H<sub>4</sub> in the case of Fischer Tropsch synthesis) are converted into the desired product. While heavy hydrocarbons cause fouling, other hydrocarbons can have negative effects on the downstream catalytic process due to the risk of deactivation. For the production of SNG the presence of hydrocarbons is an advantage, because most of the hydrocarbons are present as CH<sub>4</sub> and the other hydrocarbons can be converted into methane with a higher efficiency than the conversion of syngas into CH<sub>4</sub>. Hence, medium temperature gasification is the more logical choice for production of Bio-Methane.

The medium temperature gasifiers can be divided in fixed bed down-draft gasifiers and fluidized bed gasifiers. Down draft bed gasifiers are widely used to generate gas for gas engines. The advantage of this type of gasifier is its simplicity and low investment cost. Down-draft gasifiers require a well defined fuel to keep the bed of fuel particles flowing nicely downwards. Scale-up is limited to typically below 1 MW<sub>th</sub> biomass input. The conversion of the fuel is limited.

Fluidized bed gasifiers can handle a wide variety of fuels. This technology is the more logical choice for large scale applications such as the production of Bio-Methane. Fluidized Bed gasifiers can be divided into three main categories: Bubbling Fluidized Bed (BFB), Circulating Fluidized Bed (CFB) and Indirect or Allothermal twin bed concepts. All Fluidized Bed gasifiers use a bed material. That can be ordinary sand, the ash from the fuel or a catalytically active bed material like dolomite or olivine. The purpose of the bed material is to distribute and transport the heat in the gasifier which prevents local hot spots, mix the fuel with the gasification gas and the produced gases and, in the case of a catalytically active material, reduce the concentration of tars. Figure 3 shows the basic principles and differences of three types of Fluidized Bed gasifiers.

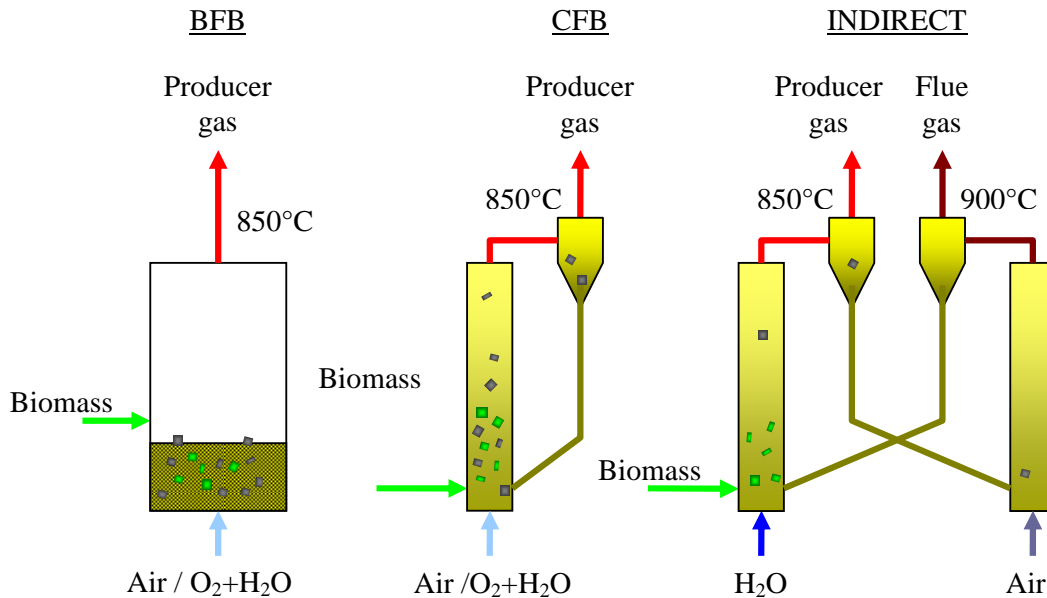


Figure 3: Schematic comparison of BFB, CFB and Indirect gasification

In a BFB gasifier the fuel is normally fed in or above the fluidized bed. The bed material is fluidized by a gas (air or an oxygen steam mixture) entering the gasifier through nozzles distributed over the bottom of the reactor. The air is used in the bed to combust part of the gas and/or the char to produce the heat required for heating the biomass and the endothermic gasification processes. The typical gas velocity in this gasifier is 1 m/s.

At higher gas velocities, the bed material gets entrained and a circulation of the bed material is required. This type of gasifiers is called Circulating Fluidized Bed (CFB) gasifiers. Typical velocity in the gasifier is between 3 and 10 m/s. The entrained bed material and the not completely converted fuel particles (char) are removed from the produced gas by a cyclone or another separation device. The particles are normally returned to the bottom of the gasifier.

Separating the gasification of the biomass and the combustion of the remaining char leads to the Indirect or Allothermal gasification process as shown in the right part of Figure 3. The biomass fed to the 'gasifier' is converted into a gas and char. The heat required for the heating of the biomass comes from the combustion reactor. This heat is transported by the circulating bed material. Char and bed material are separated from the gas by a solid gas separation device (e.g. a cyclone). The produced gas exits the gasifier to the gas cleaning. The char and bed material are fed to the combustion reactor. The char is combusted to produce the required heat for the gasification reactor. The heated bed material is returned to the gasifier reactor again. The fuel conversion in indirect gasifiers is higher than in CFB or BFB gasifiers (direct gasifiers) because all the char is combusted. The remaining ash contains virtually no carbon, which benefits the overall efficiency of the process.

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.

- **Most suitable gasification technology for Bio-Methane production**

ECN made a comparison between the different biomass gasification technologies to determine which one is most promising for the production of Bio-Methane [4]. Overall efficiency is seen as one of the most important criteria. Figure 4 shows the calculated overall efficiencies for the different biomass gasification technologies. The compared technologies are:

1. Pressurized Entrained Flow (EF) in combination with fuel pre-treatment (torrefaction)
2. Pressurized steam / oxygen blown Circulating Fluidized Bed (CFB)
3. Atmospheric indirect (or allothermal) gasification.

The shown gross efficiencies exclude electricity consumption / production. The net efficiencies include the production of consumption of electricity. Because of the significant differences in overall efficiencies to SNG for the different gasifiers, ECN decided to select the Indirect (Allothermal) gasification as the preferred technology for the production of SNG. The ECN MILENA technology is an Indirect biomass gasifier. Pressurization of the indirect gasifier will further improve efficiency. Future development will focus on increasing the operation pressure of the MILENA gasifier.

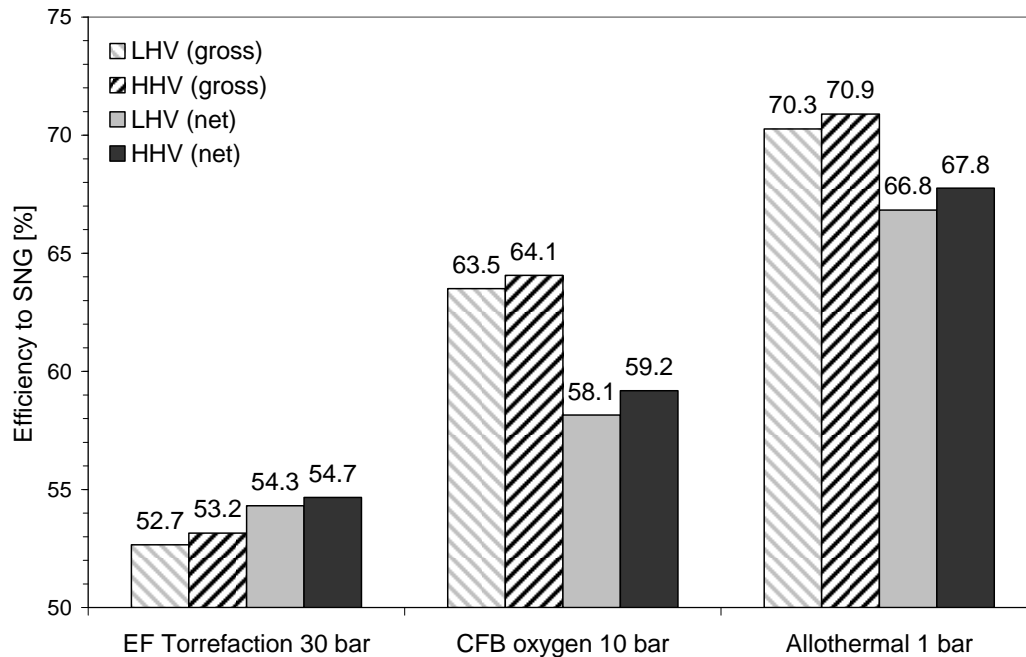


Figure 4: Gross efficiency to SNG and net efficiency to SNG and electricity.

## 4. ECONOMICS

A pre-design was made for an economical evaluation of the Bio-Methane production process. As with almost all bio-energy processes costs are mainly determined by the biomass costs, in particular at larger scales [5]. Therefore Bio-Methane production costs are calculated for biomass prices of 0 and 2

€/GJth (e.g. locally available biomass) as well as of 4 and 6 €/GJth (e.g. biomass delivered at the gate of larger power plants). Figure 5 shows the calculated productions costs for a 1000 MW<sub>th</sub> biomass input installation which produces 0.8 bcm / year of Bio-Methane. The Total Capital Investment for such a plant is estimated to be 500 million €.

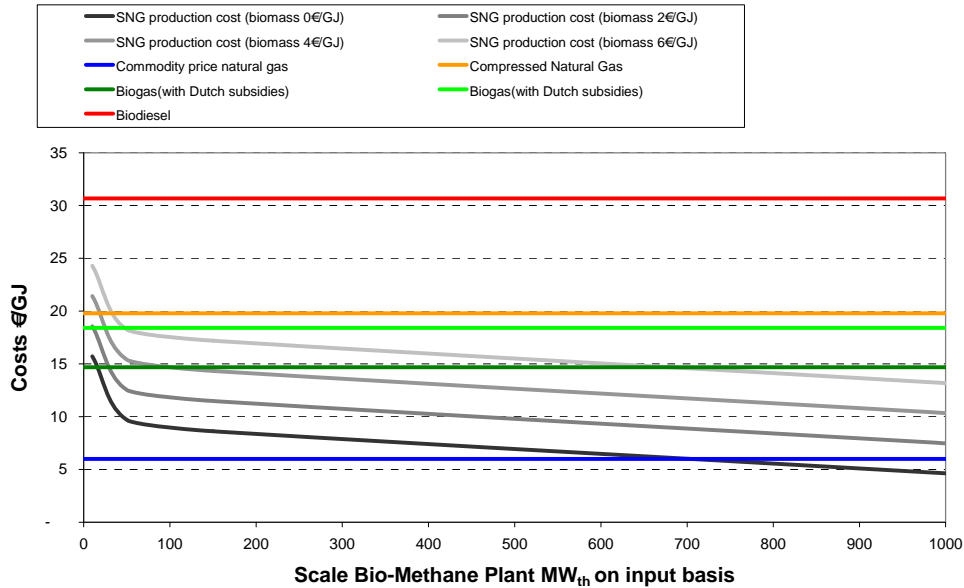


Figure 5: Production costs for Bio-Methane.

As can be seen from the figure the production costs for Bio-Methane are higher than for fossil natural gas (assumed natural gas price of 6 €/GJ or ±6 €/MMBTU) when no subsidies or CO<sub>2</sub> credits are taken into account. The cost for Bio-Methane decreases at larger scale, because the investments costs for the Bio-Methane production plant are strongly reduced on MW<sub>th</sub> basis when the technology is scaled up. Because of the urgent need of reducing CO<sub>2</sub> emissions and replacing declining fossil fuels reserves it is to be expected that local governments will continue the incentives that were introduced to promote sustainable energy. Bio-Methane can easily compete with other sustainable alternatives like Bio-diesel and Bio-ethanol.

## 5. MILENA BIO-METHANE DEVELOPMENT

- **MILENA gasifier and OLGA gas cleaning**

The MILENA [6] is an Indirect (or Allothermal) gasifier, it contains separate sections for gasification and combustion. Figure 6 shows a simplified scheme of the MILENA Bio-Methane process. If the moisture content of the biomass is too high (>30 wt% moisture) the biomass needs to be dried to approximately 25 wt% moisture. Residual heat can be used to dry the biomass, this increases overall efficiency.

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 the figure 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 is added from below. Hot bed material (typically 925°C sand) enters the riser from the combustor through a hole in the riser (opposite and just above the biomass feeding point). The bed material heats the biomass to 850°C. The heated biomass particles are converted into gas, tar and char. The volume created by the gas from the biomass results in a vertical velocity of approximately 6 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. Typical residence time of the gas is several seconds.

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.

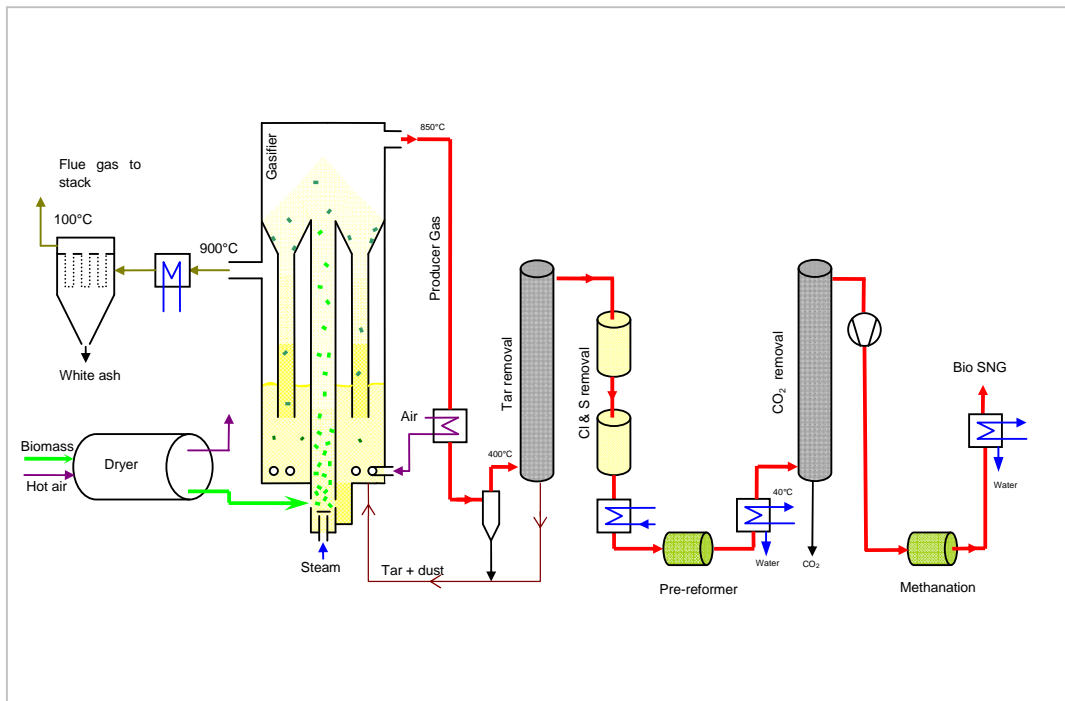


Figure 6: Simplified scheme of MILENA Bio-Methane configuration.

The hot producer gas from the gasifier contains several contaminants such as dust, tar, chloride and sulfur, which have to be removed or lowered in concentration before the gas can be used. All fluidized bed gasifiers produce gas which contains some tar. Tar compounds condense when the gas is cooled, which makes the gas very difficult to handle, especially in combination with dust. The producer gas is cooled in a heat exchanger, designed to treat gas which contains tar and dust. The heat is used to pre-heat combustion air. Tar and dust are removed from the gas in the OLGA gas cleaning section [7]. Tar removal is an essential process step. ECN spent many years in testing /

developing different tar removal concepts, before the OLGA system was developed [8]. The OLGA process is now commercially available from Dahlman ([www.dahlman.nl](http://www.dahlman.nl)). 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 partially cleaned producer gas, containing mainly CO, CO<sub>2</sub>, H<sub>2</sub>, H<sub>2</sub>O, CH<sub>4</sub>, C<sub>2</sub>H<sub>4</sub>, C<sub>6</sub>H<sub>6</sub> and low concentrations of sulfur and chloride species can be used in gas engines. For further catalytic upgrading into Bio-Methane deep removal of sulfur and chloride species is required. Several options are available for sulfur and chloride removal. The final steps normally consist of adsorbents such as ZnO for removal sulfur down to ppb level.

Methanation of the gas is done in catalytic reactors using nickel catalysts. The configuration shown in the figure assumes a pre-reforming step prior to the methanation step. In the pre-reforming step the higher hydrocarbons (e.g. benzene) are converted into a mixture of CH<sub>4</sub>, CO, CO<sub>2</sub>, H<sub>2</sub>O and H<sub>2</sub>. Conversion of the higher hydrocarbons makes the removal of CO<sub>2</sub> and the compression easier. After CO<sub>2</sub> and H<sub>2</sub>O removal the gas is converted into Bio-Methane. The configuration of the methanation unit is still under discussion. The different suppliers of methanation technology prefer different configurations. The configuration shown here is the basis of the experimental setup at ECN.

Overall energetic efficiency of the configuration shown here is expected to be around 70%.

- **Experimental facilities and results**

ECN produced the first Bio-Methane in 2004, using a conventional fluidized bed gasifier. The lab-scale MILENA gasifier was built in 2004. The installation is capable of producing approximately 8 Nm<sup>3</sup>/h methane-rich medium calorific value gas with high efficiency. The following biomass fuels were successfully tested: wood, sewage sludge and lignite. The lab-scale gasifier is coupled to lab-scale gas cleaning installations (including OLGA) and a methanation unit. The lab-scale gasifier and connected gas cleaning have been operated successfully during several 100 and 200 hour duration tests. Testing of different process conditions and catalysts is an ongoing activity. Figure 7 shows an example of the measured gas composition after the lab-scale methanation test rig (without CO<sub>2</sub> removal).

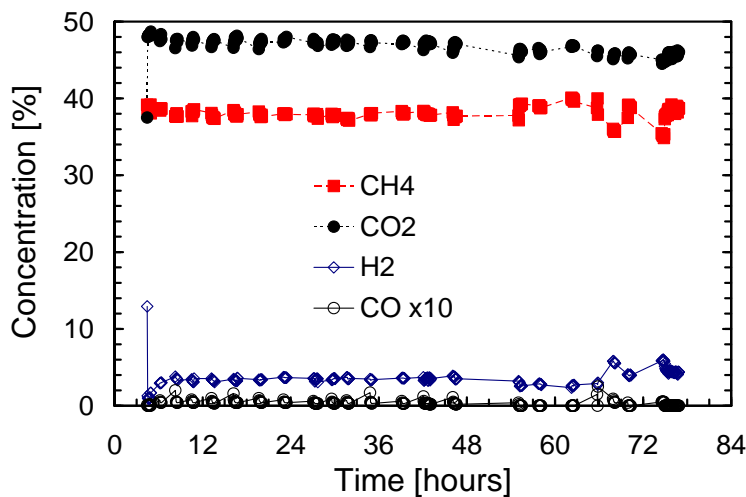


Figure 7: Gas composition before CO<sub>2</sub> removal.

A pilot scale MILENA gasification unit of 160 kg/hour (800 kW<sub>th</sub>) was taken into operation in the summer of 2008. Figure 8 shows the MILENA and OLGA pilot plant. The plant has been used extensively to generate engineering data for the Bio-Methane demonstration plant. Different woody fuels were tested. Adaptations were made to solve initial problems with the design. A 250 hour test was done in 2010 using demolition wood.



Figure 8: Pilot-scale MILENA gasifier (left) and installation of the OLGA pilot-scale gas cleaning (right).

Results from lab-scale and pilot scale tests were used to design commercial size Bio-Methane installations. Table I shows the calculated gas compositions when (residual) wood with 25% moisture is converted in the MILENA gasifier into producer gas and the producer gas is catalytically converted into Bio-Methane. Exact specifications for injection of the gas in the grid varies per region. In most cases the gas composition can be adapted to meet the specification. The allowable H<sub>2</sub> content in the Bio-Methane is still a topic of discussion. The hydrogen content can be lowered by adapting the process conditions or removal of the hydrogen.

CO	[vol.%]	0.0
H <sub>2</sub>	[vol.%]	1.2
CO <sub>2</sub>	[vol.%]	0.4
O <sub>2</sub>	[vol.%]	0.0
CH <sub>4</sub>	[vol.%]	93.4
N <sub>2</sub>	[vol.%]	4.6
LHV	[MJ/nm <sup>3</sup> ]	33.7
HHV	[MJ/nm <sup>3</sup> ]	37.4
Overall efficiency (LHV) basis	[%]	68.3

Table I: Calculated gas composition and heating values of Bio-Methane produced by gasification.

## 6. BIO-METHANE DEMONSTRATION PROJECTS

In Europe several Bio-Methane demonstrations projects using gasification technology are under development. All of these projects use low temperature fluidized bed gasification technology.

- **SNG Demonstration in Güssing**

For the complete value chain demonstration from woody biomass to SNG a 1 MW SNG demonstration plant was built and operated in Güssing, Austria by a Swiss-Austrian consortium. The methanation unit was developed by the Paul Scherrer Institute (PSI) and CTU. The methanation unit was fed with producer gas from the Indirect FICFB gasifier in Güssing.

- **The GoBiGas project**

The Gothenburg Biomass Gasification Project (GoBiGas) will be built by Göteborg Energi and E.ON. The gasification plant is scheduled to be built in two stages, the first stage (about 20 MW of gas) to be built during 2010-2012 and to be operational in 2013. The second stage (about 80 MW gas) will be built when the first plant is successfully in operation.

- **HVC Bio-Methane demonstration plant**

The Bio-Methane demonstration plant (in Dutch: Groen Gas Centrale) will be built by a consortium consisting of HVC, ECN, Dahlman and several other companies interested in Bio-Methane. HVC Group (situated in Alkmaar, North Holland) is a modern public service waste and energy company. HVC converts waste streams which cannot be recycled into usable forms of energy. HVC has a large fluidized bed waste wood boiler in operation, which produces heat and electricity. HVC expects an important role for Bio-Methane in the future. HVC plans to supply the produced Bio-Methane to its clients. HVC is also involved in several projects converting biogas from anaerobic digestion plants into gas grid quality Bio-Methane. ECN is a research institute, and is responsible for the development of the MILENA gasification technology and the OLGA tar removal technology. Dahlman ([www.dahlman.nl](http://www.dahlman.nl)) is the commercial supplier of the OLGA gas cleaning technology and is responsible for the basic engineering of the integrated MILENA OLGA plant. The technology supplier for the methanation unit is not selected yet. Several commercial companies have expressed that they can convert the cleaned gas into methane.

Discussion with several other large commercial companies are ongoing to join the consortium to realize the demonstration plant. The demonstration plant will be part of the Biomass Gasification Expert Centre and will include facilities to test new conversion technologies. Changes in the plans, extension of the consortium and a possible change in location have delayed the project somewhat. Construction of the demo plant is now scheduled for 2013. Figure 9 shows the MILENA gasifier as designed for the demonstration plant in Alkmaar. The capacity of the plant will be 12 MW<sub>th</sub> biomass input. Expected output of Bio-Methane is 0.01 bcm/year. The next step will be a plant of approximately 50 MW<sub>th</sub> (0.04 bcm/year). The scale foreseen for a commercial single-train Bio-Methane production facility is between 50 and 500 MW<sub>th</sub> (0.04 – 0.4 bcm/year).

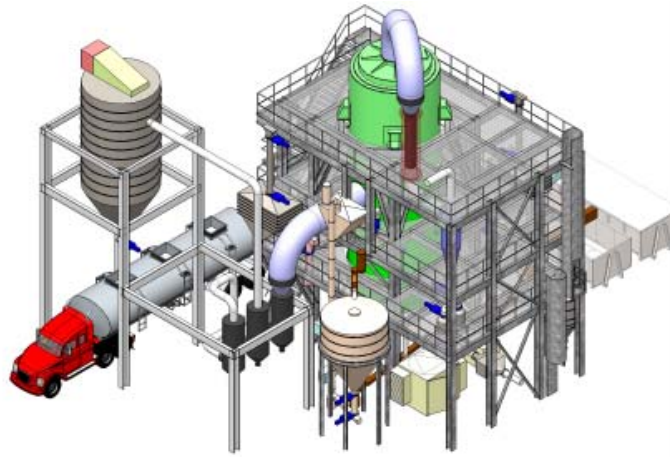


Figure 9: MILENA 12 MW<sub>th</sub> gasifier.

## 7. CONCLUSIONS

Production of Bio-Methane by gasification of woody biomass is an attractive option to replace fossil fuels and reduce CO<sub>2</sub> emissions. In combination with CO<sub>2</sub> sequestration net CO<sub>2</sub> 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.

Bio-Methane can be used in the transport sector as CNG. The price of Bio-Methane is higher than of natural gas, but can easily compete with the other bio-fuels like Bio-Diesel and Bio-Ethanol.

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

The development of the Bio-Methane production technology by gasification is on schedule. Lab-scale and pilot-scale testing has been done. A demonstration project in Alkmaar (the Netherlands) on a scale of 12 MW<sub>th</sub> (approx. 0.01 bcm/year) is under development. Scheduled start of construction is 2013.

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