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PRODUCTION OF BIO-CNG BY GASIFICATION

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ABSTRACT: Compressed Natural Gas (CNG) is becoming more and more important as a transport fuel. The number of cars using CNG instead of liquid fuels is increasing rapidly (to 8 million in 2008). CNG is a relatively clean transport fuel. The emissions of CO_2, particles and sulfur are significantly lower than for other conventional fossil fuels. Fossil CNG can easily be replaced by CNG produced from biomass (Bio-CNG), because the composition of the gas and the heating value are similar. Replacing CNG by Bio-CNG will reduce fossil CO_2 emissions to zero. Bio-CNG even has the potential to become a CO_2 negative transport fuel, as part of the carbon from the biomass is separated as pure CO_2 from the fuel during the production of Bio-CNG. If this pure CO_2 stream is sequestrated, Bio-CNG becomes CO_2 negative.

The production of Bio-CNG via digestion has been developed and is implemented (mainly) in small-scale installations. The limited amount of suitable digestible feed stock demands for development of a technology which can convert a wider range of biomass, like wood residue, into Bio-CNG. Gasification is such a route that can convert a wide range of (cellulosic) biomass into CH_4 with a high energetic efficiency of 70%. A promising alternative second generation bio-fuel is Fischer-Tropsch Diesel produced by gasification of biomass, but the overall efficiency of biomass to Fischer-Tropsch Diesel is significantly lower (below 50%).

Several biomass gasification technologies are available or under development to produce gas that can be upgraded into Bio-CNG. The overall system from biomass (wood) to SNG was modeled using Aspen Plus. The results showed that indirect gasification gives the highest overall efficiency to Bio-CNG

The Energy research Centre of the Netherlands (ECN) decided to continue the development of an indirectly heated (allothermal) biomass gasification process (MILENA), because of its high overall efficiency to Bio-CNG. The foreseen scale for a commercial Bio-CNG production facility is between 50 and 500 MW_{th} or between 3 and 30 ton/h of Bio-CNG. The MILENA technology is suitable to be scaled up to this scale. ECN also develops and tests the required gas cleaning equipment. The gas from the final gas cleaning step can directly be upgraded into CH_4 by conventional and commercially available methanation catalysts.

ECN has built and tested the Bio-CNG installation on a lab-scale of 6 kg/hour biomass input (30 kW_{th}). A pilot scale gasification unit of 160 kg/hour (0.8 MW_{th}) was built in 2008. First tests in biomass combustion and gasification mode showed that the installation is behaving as expected. The results from the lab-scale installation are promising. The gasifier and connected gas cleaning were operated successfully during several 100 hour duration tests. Progress has been made in selecting the appropriate process conditions to obtain cleaned producer gas that can be sent to a commercial methanation process.

Keywords: allothermal conversion, biomass conversion, bio-syngas, gasification, methane, bio-cng.

1 INTRODUCTION

Natural gas is a popular fuel, because it is clean and safe. The usage of natural gas is increasing. The composition of natural gas varies, but the main component is always methane.

Natural gas can also be used as transport fuel by compressing the gas (Compressed Natural Gas, CNG) or by liquefying the gas (Liquefied Natural Gas, LNG). CNG is mostly used in passenger cars. LNG is often used in heavy trucks and busses, but they can also use CNG. The number of cars using natural gas instead of an oil based fuel is increasing by almost 30% per year. In 2008 8 million cars were fueled by natural gas.

Natural gas from fossil origin can easily be replaced by a Substitute Natural Gas produced from biomass (Bio-SNG), because the composition of the gas and the heating value are similar [1]. Compression of this gas to 250 bar converts the gas into Bio-CNG and makes the gas suitable for transport applications. If the Bio-SNG is liquefied it becomes Bio-LNG.

Biomass is considered a CO_2 neutral fuel, as the amount of CO_2 released on burning biomass equals the amount taken from the atmosphere during growth of the biomass. Replacing natural gas by Bio-SNG will reduce fossil CO_2 emissions to zero. Bio-SNG has the potential to become a CO_2 negative fuel, because part of the biomass carbon is separated as CO_2 in the Bio-SNG production process. If this pure CO_2 stream is sequestrated, Bio-SNG becomes CO_2 negative.

The European Union has proposed to replace 15% of the fuels used for transportation by Bio-fuels and 10% by natural gas. Bio-CNG is an interesting fuel to fill in both targets.

The production of Bio-SNG or Bio-CNG via digestion has been developed and is implemented (mainly) in small-scale installations. Because of the limited amount of suitable digestible feed stock, there is a demand for development of a technology which can convert a wider range of biomass feed stocks into Bio-SNG. Gasification is a route which can convert a wide range of biomass feed stocks into CH_4 with a high energetic efficiency. Gasification processes can use a variety of non food crops. These include husks, (waste) wood and different energy crops.

The future world-wide available amount of biomass for energy is estimated to be 200 to 500 EJ per year [2]. Word wide yearly oil consumption was approximately 160 EJ (82.5 million barrels of oil per day) in 2005.

ECN is developing an indirectly heated (allothermal) biomass gasification process (MILENA), optimized for the production of Bio-SNG or Bio-CNG [3]. The

technology is based on fluidized bed gasification. Fluidized bed gasification is widely used to produce gas which is fired in gas boilers and gas engines. The gas produced in fluidized bed gasifiers is not directly suitable to replace conventional natural gas, because the raw gas contains CO, H_2, several hydrocarbons and pollutants like chloride, sulfur, tars and dust. Moreover, most conventional fluidized bed gasifiers produce a gas which contains a large amount of N_2. This makes this raw gas unsuitable for upgrading into SNG or CNG. For SNG or CNG production, such gasifiers have to be operated with pure O_2. Indirect or Allothermal Fluidized Bed gasifiers can operate with air and still produce a gas virtually free of N_2. After removal of the pollutants the remaining mixture of CO, CO_2, H_2, H_2O, CH_4 and other hydrocarbons can be catalytically converted into Bio-CNG.

The work done at ECN focuses on the development of the MILENA gasification technology for large scale production of gas which can be upgraded into Bio-SNG / Bio-CNG. Gas from the MILENA gasifier contains tar. Tars become sticky when the gas is cooled down and pollute water when the water in the gas is condensed. The selected tar removal technology is the OLGA technology [4] which was jointly developed by ECN and Technisch Bureau Dahlman and is currently commercially available.

The gas from the final gas cleaning step can directly be upgraded into CH_4 by conventional and commercial methanation catalysts.

The foreseen scale for a commercial Bio-SNG / Bio-CNG production facility is between 50 and 500 MW_{th} or between 3 and 30 ton/h of SNG / CNG. The expected overall efficiency from biomass to SNG is approximately 70%.

2 OVERALL BIO-CNG SYSTEM

A simplified overall process scheme for the production of Bio-SNG / Bio-CNG is shown in Figure 1.

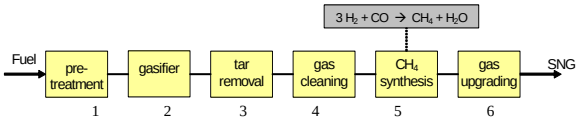

Figure 1: Simplified overall process

The following process steps are required to produce Bio-SNG:

1. Pre-treatment of the biomass e.g. drying, torrefaction, chipping and/or milling .
2. Gasification, solid biomass is converted into a producer gas or syngas.
3. Gas cooling and tar removal (gas from an entrained flow gasifier does not contain tar).
4. Further gas cleaning, impurities like sulphur, chloride and dust need to be removed before the synthesis.
5. Catalytic conversion of the gas into methane.
6. Gas upgrading, removal of CO_2 and H_2O and compression to final gas grid pressure or CNG fueling pressure.

Several gasification processes are under development or are commercial available for gasification of biomass. The most well known gasification processes suitable for large scale are: 1) Entrained Flow, 2) Circulating Fluidized Bed and 3) Allothermal or Indirect gasification. All three gasifier types deliver gas suitable for upgrading to SNG, but the type of gasifier has a significant effect on overall efficiency. Downdraft gasification was not considered because this technology is not suitable for scale-up. Updraft gasification was not considered because no demonstration or commercial plant is known using biomass as feed and oxygen as gasification agent.

The three different gasifiers coupled to the required gas cleaning, methanation and gas upgrading steps were modeled using Aspen Plus taking into account experimental data. The most suitable gasification technology was selected based on the results from these models. The results are described in paragraph 2.1.

2.1 Selection of optimal gasification process for SNG

ECN has selected indirect gasification as a promising gasification technology for the production of SNG in 2003 [5]. This gasification technology was selected because the methane yield is relatively high and the fuel is completely converted into gas, which has a positive effect on overall efficiency to SNG. The development of an indirect gasifier (MILENA) was already started for gas engine applications, so choosing indirect gasification for SNG as well was logical.

The difference in overall efficiency, compared to other promising gasification technologies like entrained flow and Circulating Fluidized Bed (CFB), was never quantified. In 2008 a study was done to quantify these differences [6]. A summary of the results from this study is given here. Dry wood (moisture content = 15 wt.%) was selected as the fuel for this comparison, as it can be used for all three different types of gasifiers.

The different gasification technologies coupled to the required gas cleaning and gas upgrading steps were modeled using the experimentally validated ECN gasification model and Aspen Plus. The different gasification technologies require different gas cooling and gas cleaning technologies, but the further gas upgrading was kept as similar as possible.

Entrained flow gasification is has been widely used, at a large scale, to convert coal in syngas. A well known commercial Entrained Flow gasifier is the Shell gasifier in Buggenum, the Netherlands. This gasifier was build to produce syngas from coal. The syngas is combusted in a gas turbine to produce electricity. Up to 30 mass% of biomass has been mixed with coal and fed into the gasifier to produce green electricity, however 100% biomass firing has not been reached yet.

Entrained flow gasification requires an energy intensive pre-treatment step to produce a fine dry powder, which can be fed into the gasifier. Torrefaction is seen as the most logical pre-treatment step for Entrained Flow gasification [7]. The energy required for milling the fuel is significantly reduced and the fuel contains less water, which improves the cold gas efficiency (energy in cold gas / energy in biomass) of an Entrained Flow gasifier. Torrefaction also reduces transportation and storage costs for biomass [8]. A disadvantage of this pre-treatment step is the loss in calorific value of the biomass and the electricity consumption for the process, but these losses are compensated by the reduction in required milling

energy, improved cold gas efficiency and gains in transportation and handling costs.

The fine particles are pneumatically fed into the gasifier using an inert gas. CO_2 is chosen as inert gas, because CO_2 becomes available in the SNG upgrading process and (conventionally used) nitrogen is not an option because it would dilute the final SNG. The temperature in an Entrained Flow gasifier is relatively high, because the gasifier needs to operate above the melting point of the ash. A gasification temperature of 1300°C is assumed to be sufficient for biomass, if a fluxing agent is added to the biomass to keep the viscosity of the liquid ash low enough [9]. At 1300°C a syngas is produced containing mostly CO, H_2, CO_2 and H_2O. The gas contains almost no hydrocarbons like CH_4. The gasification process requires pure oxygen as gasification agent. Oxygen is produced in an Air Separation Unit (ASU), an electricity consumption for the production is taken into account. Entrained Flow gasifiers are operated at elevated pressures, for the study a typical operating pressure of 30 bar for solid fed Entrained Flow gasifiers was assumed.

Several air-blown CFB gasifiers are in operation using biomass or waste as fuel. A well known example is the Foster Wheeler gasifier in Ruien, Belgium [10]. For the production of SNG a nitrogen free gas is required. Using a steam / oxygen mixture instead of air makes it possible to produce a nitrogen free gas. The selected steam to oxygen ratio is 1 (kg/kg). It should be noticed, however, that this assumption has a major impact on overall efficiency. VTT in Finland has built a pressurized steam / oxygen blown CFB biomass gasifier, but at this moment no experimental results are available in the public domain. ECN has previously done some experiments with atmospheric steam / oxygen blown CFB gasification where the steam to oxygen ratio was taken similarly to the ratio assumed here**.** Commercial CFB gasifiers were operated at elevated pressures. It is expected that CFB gasifiers operating at 10 bars are commercially available; therefore an operating pressure of 10 bars was assumed for this study.

CFB gasifiers (±850°C) give a producer gas which in addition to CO, H_2, CO_2 and H_2O contains CH_4, unsaturated and aromatic hydrocarbons like C_2H_4, C_6H_6 and tar. The presence of hydrocarbons like CH_4 and C_2H_4 has a positive effect on overall efficiency to SNG. The disadvantage of CFB gasifiers is the limited conversion of the fuel into gas. For relatively dry wood (15 wt% moisture) a carbon conversion of 90% is assumed. This assumption is based on experimental data from the ECN CFB gasifier [11] and data from literature [12].

Indirect or allothermal gasifiers operate at the same temperature as CFB gasifiers; the operating temperature is kept below the melting temperature of the ash. In an indirect gasifier the conversion process is done in two separate reactors. Figure 2 shows the basic principles of indirect or allothermal gasification. Biomass is gasified in the first reactor. The heat required for the gasification comes from a second reactor where the char remaining from the 1st reactor is combusted.

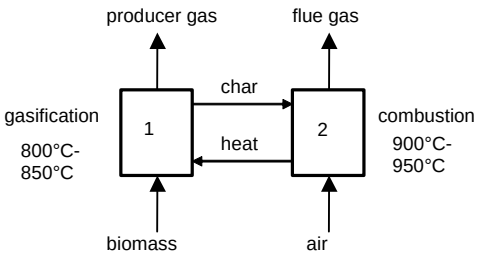

Figure 2: Schematic drawing of indirect gasification

A circulating bed material (e.g. sand or olivine) is used to transport the heat from the combustor to the gasifier and the char from the gasifier to the combustor. The producer gas from reactor 1 and the flue gas from reactor 2 leave the installation separately. Air is used for the combustion of char, because the flue gas is not mixed with the producer gas the nitrogen in the flue gas does not dilute the producer gas. The producer gas from the gasifier contains the same components as gas from a CFB gasifier, but contains less CO_2 and N_2, because the gas is not diluted with flue gas,

Indirect gasification concepts under development or demonstration are the Silvagas [13], the MILENA and the FICFB process [14]. The FICFB gasifier requires a lot of steam to gasify the biomass. This results in relatively low tar content, but creates an efficiency loss, because the steam is heated up to process temperature.

The Silvagas and Milena processes use small amounts of steam, but produce more tar. Tar needs to be removed from the producer gas and is recycled to the combustor reactor of the gasifier. For this study a Silvagas or Milena type indirect gasifier was selected, because of the lower steam requirement (5wt% of amount of biomass added) resulting in a higher efficiency.

The overall efficiencies to SNG are calculated on a net and gross basis. Gross efficiency does not take into account the electricity production or consumption of the system. To calculate the net efficiency the electricity consumed (or produced) is assumed to be produced by converting SNG into electricity with an efficiency of 60% for electricity generation. Figure 3 shows the calculated overall efficiencies on Higher Heating Value (HHV), for the three different gasifiers operating at different pressures, of biomass to SNG at 30 bar. As can be seen from the figure the gross efficiencies to SNG are relatively low for pressurized Entrained Flow gasification. The net efficiency is higher, because the system produces electricity. The other two systems consume electricity. The reason for the net electricity production in the EF based system is the significantly higher production of steam in both the syngas cooler and the methanation unit.

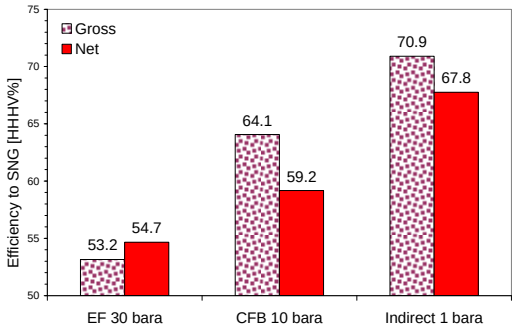

Figure 3: Calculated efficiency to SNG

Gross and net overall efficiencies are highest for the atmospheric Indirect gasifier. These high values are due to the complete conversion of the fuel into gas and the fact that the gas from the gasifier already contains a significant amount of hydrocarbons.

The overall efficiency of the system based on indirect gasification can be increased by integrating a biomass drying step using low temperature waste heat and by a slight increase of gasification pressure (e.g. to 3 bar instead of 1 bar). Overall efficiency can increase to over 70% if both measures are combined.

Bio-SNG is converted into Bio-CNG by compressing the gas from 30 bar to 250 bar. The compression step reduces the overall efficiency by 1%.

3 MILENA GASIFICATION PROCESS

ECN started to work on gasification in 1987. A downdraft gasifier was constructed and operated to produce gas for gas cleaning tests (H_2S removal). This downdraft gasifier was later used for biomass gasification research. In 1996 the 500 kW_{th} Circulating Fluidized Bed (CFB) gasifier BIVKIN [3] was constructed and taken into operation. The BIVKIN installation was tested on wood pellets, wood chips, demolition wood, sewage sludge, sunflower husks, wheat straw, chicken manure, pig manure and paper sludge. The limited fuel conversion of a CFB gasifier, typical between 90 and 98%, was seen as a major drawback of this technology. Incomplete fuel conversion results in a loss of efficiency and an ash stream which contains combustible carbon. The producer gas from an air blown Bubbling Fluidized Bed (BFB) or CFB gasifier has a relatively low calorific value (< 7 MJ/m_n^3) this makes the application of the gas in a gas engine or gas turbine more problematic. The gas also contains a significant amount of N_2 (typical 50%), this makes upgrading the gas into SNG difficult. The experience gained by operating the BIVKIN gasifier however was very useful in order to develop the MILENA process.

The first design of the MILENA gasifier was made in 1999. First a cold flow setup, for hydrodynamic testing, was built in 2000. Financing a lab-scale installation appeared to be problematic, because there was no interest in a new gasification technology at that time. This changed when SNG was identified as a promising bio-fuel. Indirect gasification was identified as a promising technology for production of Bio-SNG / Bio-CNG [5]. The construction of the 30 kW_{th} MILENA installation was started in 2003. The installation was finished and taken into operation in 2004. Financing of the 800 kW_{th} MILENA pilot plant was approved in 2006 and the construction was finished in 2008.

The MILENA gasifier contains separate sections for gasification and combustion. Figure 4 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 4 represent the circulating bed material. The processes in the gasification section will be explained first.

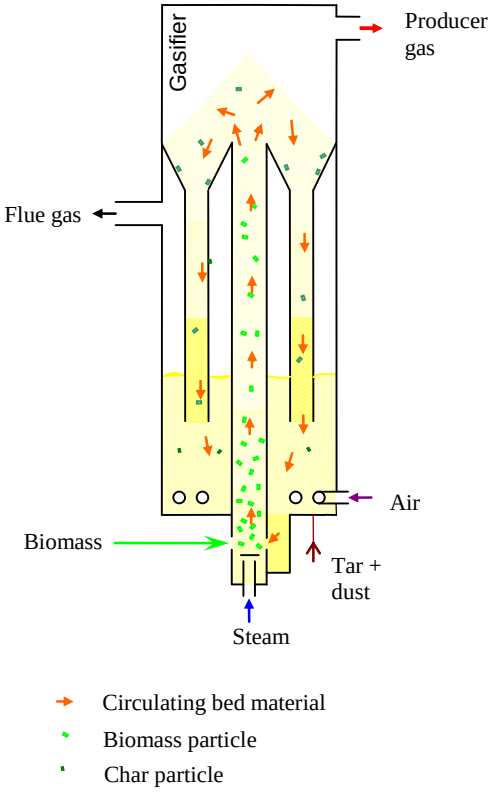

Figure 4: Simplified scheme of MILENA gasifier

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 or olivine of 0.2 – 0.3 mm) enters the riser from the combustor through a hole in the riser (opposite and just above of the biomass feeding point). 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 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 and tar 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-SNG / Bio-CNG. 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 [15]. 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, containing mainly CO, CO_2, H_2, CH_4, C_2H_4 and C_6H_6 can be used in gas boilers, gas engines, gas turbines or fuel cells or can be catalytically upgraded into SNG / CNG or syngas. Syngas can be converted into Fischer-Tropsch diesel.

The overall theoretical cold gas efficiency of the gasification process including tar removal is 78% on LHV basis and 76% on HHV basis when wood chips with 25wt% moisture are used as fuel. Efficiency can be improved by using low temperature heat for biomass drying.

Further conversion of the cleaned producer gas into a mixture of CH_4, CO_2 and H_2O is done in catalytic reactors. After compression and removal of the H_2O and CO_2 the Bio-SNG is ready for gas grid injection or can be used as transport fuel (Bio-CNG).

3.1 Lab-scale results

ECN realized a 30 kW_{th} lab-scale MILENA gasifier in 2004, capable of producing approximately 8 m_n^3/h methane-rich medium calorific gas with high efficiency. The installation consumes approximately 6 kg/h of biomass. In general dry beech wood particles between 0.75 and 3 mm are used as fuel, but also sewage sludge and grass were tested.

The internal diameter of the riser (gasifier) is 36 mm. The internal diameter of the combustor is 250 mm. The lab-scale installation is made of stainless steel (grade 253MA). Heat loss from the process is compensated by high temperature electrical trace heating and external insulation.

The riser is fluidized with steam. The amount of fluidization steam varies between 0.1 and 2 kg/h. The amount of steam required to fluidize the riser is low (0.1 kg/h), but additional steam is used to increase the water content of the producer gas, because the biomass used for lab-scale experiments is relatively dry (10 wt% moisture), the fuel foreseen for commercial applications contains more moisture (25 wt%).

The MILENA lab-scale installation has been used for nearly 1000 hours as bubbling fluidized bed gasifier and allothermal gasifier. Figure 5 shows the raw gas composition of the MILENA producer gas during automated operation.

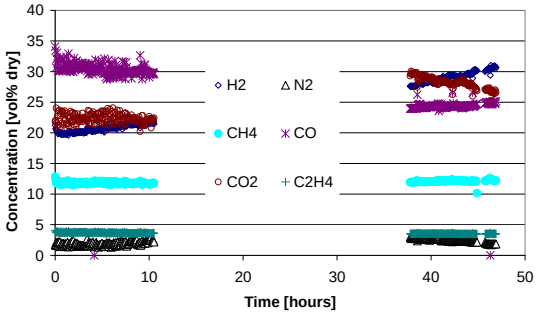

Figure 5: MILENA raw gas composition

The system was tested for 50 hours several times. During these tests part of the gas was sent to the lab-scale OLGA gas cleaning facility and methanation unit. An example of the measured raw gas composition after the MILENA gasifier is given in Figure 5. No gas composition was measured, between hours 11 and 38, because the analyzers were used to measure the gas composition at several locations in the complete SNG line-up. The methane concentration was stable during the testing period. The hydrogen concentration increased over time. This increase is probably caused by an increase of CO shift activity of the bed material over time. Previous tests showed the same increase in hydrogen concentration over time. The nitrogen concentration varied between 1.4 and 3 vol% on dry basis. This variation is caused by variations in pressure difference between the combustor and the gasifier. The CO_2 concentration varied during the test, because the amount of CO_2 used to purge the feeding system was varied.

Table I gives the measured gas composition for two different bed materials (sand and Austrian Olivine) and the typical range. Olivine is known to be catalytic active in tar reduction and water gas shift reactions. The feedstock was dry beech word for both tests.

Table I: Example of measured gas compositions for different bed materials.

		Sand	Olivine	Range
CO	[vol% dr.]	39.3	21.9	20 – 43
H_2	[vol% dr.]	21.4	29.1	16 – 30
CO_2	[vol% dr.]	13.9	29.3	10 - 30
CH_4	[vol% dr.]	12.8	11.0	10 – 15
C_2H_y	[vol% dr.]	5.1	3.9	4 – 6.5
C_6H_6	[vol% dr.]	1.2	1.0	0.8 – 1.3
C_7H_8	[vol% dr.]	.1	.1	0.1 – 0.2
N_2	[vol% dr.]	5.6	2.8	0.4 – 7
Total tar	[g/m_n^3 dr.]	31.9	23.6	20 - 40

The CO_2 concentration in the gas, when using olivine as a bed material, is relatively high because of the CO shift reaction and transport of oxygen from the combustor to the gasifier by the circulating bed material. The bed material is oxidized in the combustor and reduced in the

gasifier. The gas composition is strongly influenced by the operating temperature of the gasifier, the type of bed material and the amount of steam in the gas.

3.2 Milena 800 KW_{th} pilot plant

The MILENA pilot plant was designed to replace the 500 kW_{th} BIVKIN gasifier [3], which was used for ten years. The BIVKIN gasifier was extensively used to develop and test several new gas cleaning technologies. This resulted in the OLGA tar removal technology [2]. The same OLGA pilot plant that was tested behind the BIVKIN gasifier will be used to clean the gas from the MILENA pilot plant.

The goal for the pilot plant is to realize an installation which could be used to do experiments under realistic 'commercial' conditions. This means no external heat supply to the reactor and an increase in fuel particle size from 1 – 3 mm for the lab scale installation to <15 mm for the pilot plant. The lab scale installation is limited in fuel particle size because of the size of the feeding screw and riser reactor. For the pilot plant an upper size limit of 15 x 15 mm was selected based on experiments with the 500 kW_{th} CBF gasifier.

A simplified scheme of the MILENA installation connected to existing gas coolers, gas cleaning and boiler is given in Figure 6. Producer gas from the MILENA gasifier is cooled from approximately 850°C to 400°C in a double pipe cooler [7]. Most of the dust in the gas is removed by a cyclone. This dust stream contains ash, small bed material particles and char. This stream will be recycled to the MILENA combustor in the future. Tar and the remaining dust are removed from the producer gas in the OLGA gas cleaning section. Heavy tars and dust will be pumped to the MILENA combustor. The light tars are stripped with air from the OLGA absorption fluid (oil) and are used as combustion air. Ammonia, chlorides and water can be removed from the gas by the existing wet cleaning system [8]. In the past the gas was sent to a gas engine, but no further gas engine tests are planned, because tests have shown that gas engine operation is straightforward as long as the tar dew point temperature is above the lowest temperature in the gas engine gas supply system [16]. The cleaned producer gas will be combusted in a gas boiler.

The flue gas from the MILENA combustor is cooled to 200°C. Part of the heat is used to pre-heat the combustion air. The flue gas is cleaned in a bag house filter before the flue gas is sent to the stack.

The scale of the installation was determined by the existing BIVKIN gasifier. The volume flow of gas produced in the MILENA gasifier is chosen to be slightly smaller than the volume flow from the BIVKIN gasifier (190 m_n^3/h). Because of the higher heating value of producer gas from an indirect gasifier the thermal input of the MILENA gasifier increased from 500 kW_{th} to 800 kW_{th} (HHV basis). The thermal output was increased as well. Because of the increase the gas burner and boiler had to be replaced.

The basic design data for the MILENA gasifier fueled with dry wood pellets is given in Table II.

The engineering of the MILENA pilot plant started in 2005. Financing was approved at the end of 2006. The detailed engineering was done by the Engineering and Services department of ECN in the beginning of 2007. The construction of the reactor vessel was done by HoSt BV, together with Klaas Zijlstra Metaalbewerking BV.

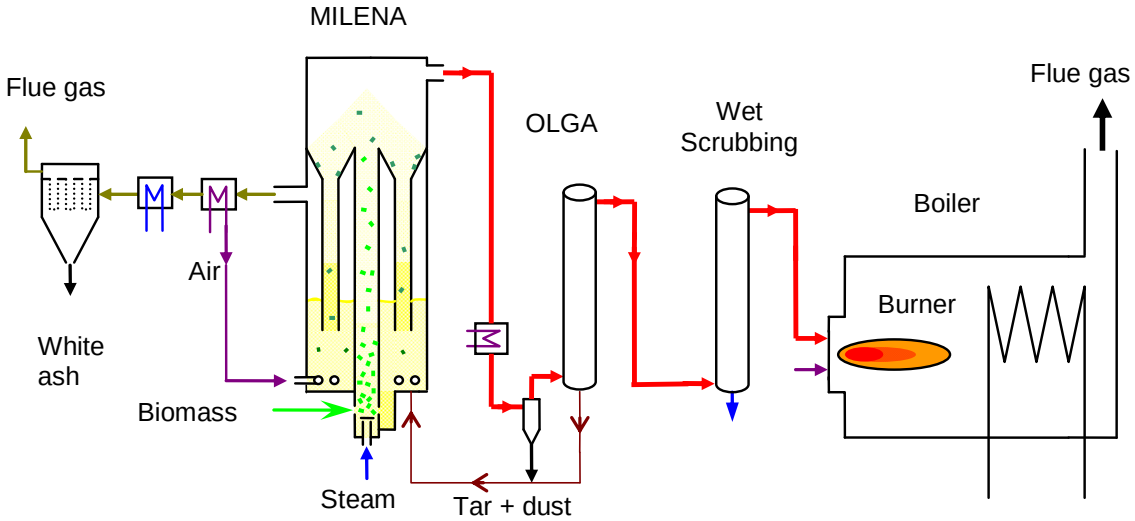

Figure 6: Schematic overview of pilot installation

Table II: Basic design data MILENA pilot plant

Thermal input (HHV basis)	[kW]	797
Biomass mass flow	[kg/h]	158
Steam to gasifier	[kg/h]	19
Riser diameter	[m]	0.2
Combustor diameter	[m]	0.8
Overall reactor height	[m]	8
Circulation rate bed material	[kg/h]	6300
Producer gas volume flow wet	[m_n^3/h]	174
Tar and BTX to combustor	[kW]	55
HHV gas wet basis excl. tar	[MJ/m_n^3]	13.1
HHV gas dry basis excl. tar	[MJ/m_n^3]	18.0

Figure 7 shows the pilot installation with the biomass feeding bunkers and the bag-house filter (left in picture).

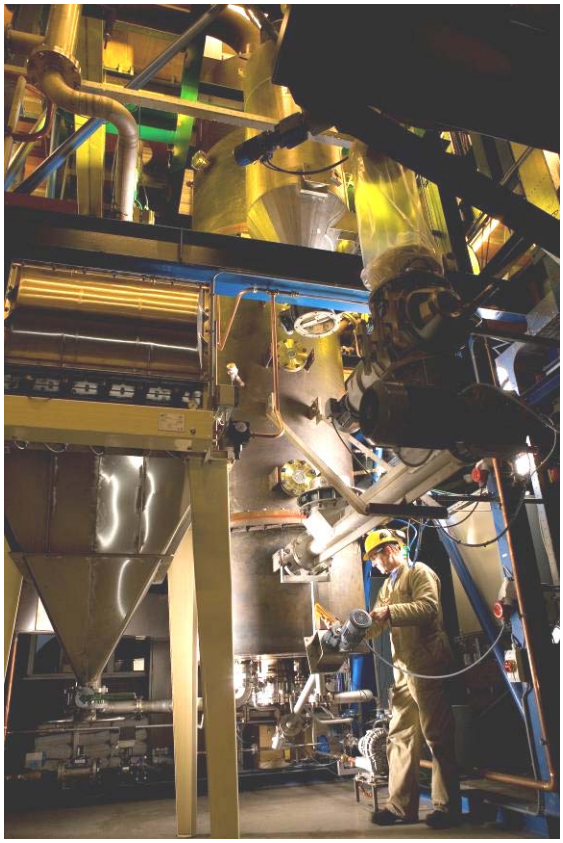

Figure 7: Milena pilot installation

First biomass combustion and gasification tests were done July 2008. These tests proved that the installation can be operated at design temperature (900°C), the circulation of solids is working well and a medium calorific value gas can be produced. First indicative measurements showed that the gas composition was according expectations. Verified results from the combustion and gasification tests were not available at the moment of writing.

4 FURTHER PLANS

Modeling activities are going on to see how overall efficiency to Bio-SNG or Bio-CNG is influenced by changing process conditions (e.g. pressure) or integrating a dryer).

The MILENA OLGA – Methanation lab scale will be extended with a CO_2 removal unit and gas compressor to bring the final gas quality up to natural gas specification. A demonstration is planned where gas from the MILENA lab scale gasifier will be upgraded to natural gas quality and will be used to fuel a conventional commercial available natural gas vehicle.

An extensive experimental program is planned for the pilot scale MILENA gasifier. Different fuels and operational conditions will be tested. A duration test of the MILENA OLGA pilot scale is scheduled fort the end of 2008.

Preparations are underway to realize a 10 MW_{th} demonstration plant, based on ECN MILENA and OLGA technology.

ECN plans to license the MILENA gasification technology to interested industrial parties when the pilot plant has proved that the technology is suitable for the next scale up step. The foreseen scale for commercial CHP units based on MILENA – OLGA technology is around 10 MW_{th}. The scale foreseen for a commercial single-train Bio-SNG production facility is between 50 and 500 MW_{th}.

5 CONCLUSIONS

The overall efficiency of biomass to Bio-SNG can be as high as 70%. Bio-SNG is converted into Bio-CNG by compressing the gas from 30 bar to 250 bar. The compression step reduces the overall efficiency by 1%. Overall efficiency is significantly higher than the overall efficiency from biomass to Fischer-Tropsch diesel (below 50%). The required infrastructure for filling CNG and the number of cars using CNG is growing rapidly. This makes Bio-CNG a promising bio-fuel for the future.

The modeling results show that indirect gasification gives the highest overall efficiency to Bio-SNG or Bio-SNG. Because of this result ECN decided to continue the development of the indirect gasifier MILENA.

The lab-scale MILENA gasifier has been in operation since 2004 and is running very well. The lab-scale installation was connected to the lab-scale gas cleaning unit (OLGA) and methanation unit. Several duration tests were done with good results. The lab-scale MILENA gasifier was extended with an automated feeding system, which makes it possible to do long duration tests without operators. This system was tested in the beginning of 2008. The gasifier is now available for long duration Bio-SNG production tests.

The construction of the MILENA pilot plant is finished. First operational test in biomass combustion and gasification mode showed that the installation is behaving as expected.

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7 REFERENCES

[1] C. M. van der Meijden, H. J. Veringa, B. J. Vreugdenhil, A. van der Drift, R. W. R. Zwart, and L. P. L. M. Rabou: Production of Bio-Methane by gasification, 2008.

[2] V. Dornburg, et. Al.: Biomass Assessment: Global biomass potentials and their links to food, water, biodiversity, energy demand and economy, main report (climate change scientific assessment and policy analysis), Netherlands Environmental Assessment Agency (MNP), WAB secretariat (ipc 90), P.O. Box 303, 3720 AH Bilthoven, The Netherlands, 2007

[3] C. M. van der Meijden, H. J. Veringa, A. van der Drift, and B. J. Vreugdenhil: The 800 KWth Allothermal Biomass Gasifier MILENA, 2008.

[4] H. Boerrigter, S. B. V. van Paasen, P. C. A Bergman, J-W. Könemann, and R. Emmen: Tar removal from biomass product gas; development and optimisation of the OLGA tar removal technology, 2005.

[5] H. Mozaffarian, R. W. R. Zwart, H. Boerrigter, E. Deurwaarder, and S. R. A. Kersten: Green gas as SNG (synthetic natural gas); a renewable fuel with conventional quality, 2004.

[6] C. M. van der Meijden, H. J. Veringa, and L. P. L. M. Rabou: Entrained Flow and Fluidized Bed Gasification of biomass to produce sustainable Synthetic Natural Gas (SNG), submitted to Biomass & BioEnergy, 2008.

[7] P. C. A. Bergman, A. R. Boersma, J. H. A. Kiel, M. J. Prins, K. J. Ptasinski, and F. J. J. G. Janssen: Torrefaction for entrained flow gasification of biomass, ECN, Petten, The Netherlands, 2005, ECN-C--05-067.

[8] R. W. R. Zwart, H. Boerrigter, and A. van der Drift: The Impact of Biomass Pretreatment on the Feasibility of Overseas Biomass Conversion to Fischer-Tropsch Products, 2006.

[9] M. K. Cieplik, B. Coda, H. Boerrigter, A. van der Drift, and J. H. A. Kiel: Characterisation of slagging behaviour of wood ash upon entrained-flow gasification conditions, ECN, Petten, 2004, ECN-CX-04-016.

[10] L. Bartsoen: CFB gasification unit in co-combustion on the Ruien coal fired power plant, United Kingdom, 2004.

[11] A. van der Drift, H. F. de Kant, and J. B. Rajani: Commercialisation BIVKIN-based gasification technology, non-confidential version, ECN, Petten, 2000, ECN-C-00-080.

[12] A. van der Drift, C. M. van der Meijden, and S. D. Strating: Hogere koolstofconversie in CFB-biomassavergassers, ECN, Petten, 2002, ECN-C-03-053.

[13] M. A. Paisley and R. P. Overend: Verification of the Performance of Future Energy Resources' *SilvaGas*® Biomass Gasifier -- Operating Experience in the Vermont Gasifier, 2002.

[14] H. Hofbauer, G. Veronik, T. Fleck, R. Ruach, H. Mackinger, and E. Fercher: The FICFB - Gasification Process, 1997.

[15] H. Boerrigter, S. V. B. van Paasen, P. C. A. Bergman, J. W. Könemann, R. Emmen, and A. Wijnands: OLGA tar removal technology, ECN, Petten, The Netherlands, 2005, ECN-report ECN-C--05-009.

[16] Verhoeff, S. V. B. Paasen, L. P. L. M. Rabou, R. Emmen, R. A. Buwalda, and H. Klein Teeselink: 700 hours duration test with integral 500kW biomass gasification system, 2007.