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SCALE-UP OF THE MILENA BIOMASS GASIFICATION TECHNOLOGY

PRESENTED AT 17TH BIOMASS CONFERENCE – HAMBURG 2009

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ABSTRACT: The Energy research Centre of the Netherlands (ECN) has developed a new biomass gasification technology, called the MILENA technology. The MILENA gasification technology combines a high cold gas efficiency of approximately 80% with a high methane yield, making it very suitable for gas engine applications or upgrading of the gas into Substitute Natural Gas (SNG).
ECN already realised a 30 kW_{th} biomass input lab-scale MILENA gasifier in 2004. This lab scale installation is connected to an oil scrubber based on the ECN OLGA tar removal technology and a downstream methanation unit. Several duration tests were done to examine the behaviour of the methanation catalyst under conditions expected during commercial applications. The results of these tests were so promising that it was decided to build an 800 kW_{th} MILENA pilot plant gasifier, which was taken into operation in 2008. First results from this pilot installation show that the gas composition is according to expectations. The pilot scale gasifier will be connected to an upscaled OLGA gas cleaning unit to test the integrated system and to make the produced gas suitable for gas engine application.
HVC Group (situated in Alkmaar, The Netherlands) is a modern public service waste company. HVC converts waste streams which cannot be recycled into usable forms of energy. HVC has a large waste wood boiler in operation which produces heat and electricity. HVC expects an important role for Bio-SNG in the future and has decided to join ECN with the development, demonstration and large scale implementation of the MILENA / SNG technology.
HVC and ECN now plan to build a 10 MW_{th} MILENA gasifier in combination with OLGA gas cleaning and a gas engine to be in operation in 2012. Woody biomass will be used as fuel. The 10 MW_{th} CHP demo is considered to be a crucial intermediate step towards commercial SNG plants. The 10 MWth CHP demo however is also considered to be a demonstration of a commercial size CHP unit. The 10 MW_{th} CHP demonstration therefore serves two goals. After a successful CHP demonstration further scale-up to a 50 MW_{th} SNG demonstration unit is envisaged. The foreseen scale for a commercial Bio-SNG production facility is between 50 and 500 MW_{th} biomass input corresponding to 3 and 30 ton/h of Bio-SNG.

Keywords: allothermal conversion, bio-syngas, gasification, methane, synthetic natural gas (SNG)

1 INTRODUCTION

ECN (Energy research Centre of the Netherlands) is developing an indirectly heated (allothermal) biomass gasification process (MILENA), optimized for the production of Bio-SNG (Substitute Natural Gas). The gasification technology can also be applied to produce gas for a natural gas boiler, fuel cell, gas engine or gas turbine. Cleaned producer gas from the MILENA gasifier can be upgraded into Bio-SNG by a catalytic process.

For the efficient production of SNG, a producer gas with a high concentration of hydrocarbons is ideal. This requires a gasification process at low temperature (below 1000°C). A low temperature air blown allothermal gasification process can produce SNG from biomass with an overall efficiency of more than 70% [1].

Most low temperature gasifiers produce a considerable amount of tar. The tar content in the producer gas can be reduced by a catalyst in-situ or downstream of the gasifier. In general, these catalysts require addition of extra steam to the gasifier to prevent the formation of soot and to enhance the steam reforming reactions. The additional steam reduces the overall efficiency of the process. ECN has chosen not to reduce the tar content catalytically and consequently to use much steam during gasification, but to physically remove the tar from the gas and to use this tar as fuel for the combustion section of the gasifier. The selected tar removal technology is the OLGA technology [2], which was jointly developed by ECN and Technisch Bureau Dahlman and currently commercially available.

The lab-scale MILENA gasifier was built in 2004. The installation is capable of producing approximately 8 Nm^3/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 tests. Progress has been made in selecting the appropriate process conditions to obtain cleaned producer gas that can be sent to a commercially available methanation process. Testing of different process conditions and catalyst is an ongoing activity.

A pilot scale MILENA gasification unit of 160 kg/hour (800 kW_{th}) was built in 2008 and was taken into operation in the summer of 2008. First results, using wood as a fuel, show that the gas composition is similar to gas from the lab-scale installation. Several modifications were required to solve mechanical problems. The pilot scale gasifier was tested when directly connected to a boiler to combust the produced gas. Soon the pilot scale gas cleaning will be connected to the gasifier in order to produce a clean gas.

The next phase of the development is demonstration of a 10 MW_{th} MILENA gasifier connected to gas engine for Combined Heat and Power production (CHP). The HVC group in Alkmaar has decided to invest in the development of the technology and is going to be the launching customer. The OLGA technology will be used to remove the tar and dust from the gas. Dahlman will supply the OLGA technology. The 10 MW_{th} demonstration is scheduled for start-up in 2012. This CHP demonstration unit is seen as an important step in the development towards Bio-SNG. The Bio-CHP technology is also seen as an attractive option for the decentralized production of heat and power. The Bio-CHP technology will become commercially available for woody biomass after the demonstration. A 50 MW_{th} Bio-SNG demonstration is foreseen after the 10 MW_{th} Bio-CHP demonstration. The HVC group will be the launching customer.

2 MILENA GASIFICATION TECHNOLOGY

ECN started to work on gasification in 1987. A downdraft gasifier was constructed and operated to produce gas for gas cleaning (H_2S removal) tests. 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 chip, 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) that makes the application of the gas in a gas engine or gas turbine more problematic. The experience gained by running the BIVKIN gasifier was used to develop the MILENA process.

The first design of the MILENA gasifier was made in 1999. The first cold flow, for hydrodynamic testing, was built in 2000. As there was no interest in a new gasification technology at that time, the financing of a lab-scale installation appeared to be problematic,. This changed when SNG was identified as a promising bio-fuel and the indirect gasification was identified as a promising technology for that [4]. The construction of the 30 kW_{th} MILENA installation started in 2003. The installation was taken into operation in 2004. Financing of the 800 kW_{th} MILENA pilot plant was approved in 2006 and the installation was taken into operation in the summer of 2008. The present activities to realize a 10 MW_{th} MILENA demonstration at the premises of the HVC group in Alkmaar were started in 2009. The gas will initially be used in a gas engine to produce heat and electricity. The start of the demonstration phase is scheduled in 2012.

The MILENA gasifier contains separate sections for gasification and combustion. Figure 1 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 small arrows in Figure 1 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 or olivine of 0.2 – 0.3 mm) 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 gasify; 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 degassed 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 finally will be emitted. The heated bed material leaves the lower part 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 and transported by the bed material.

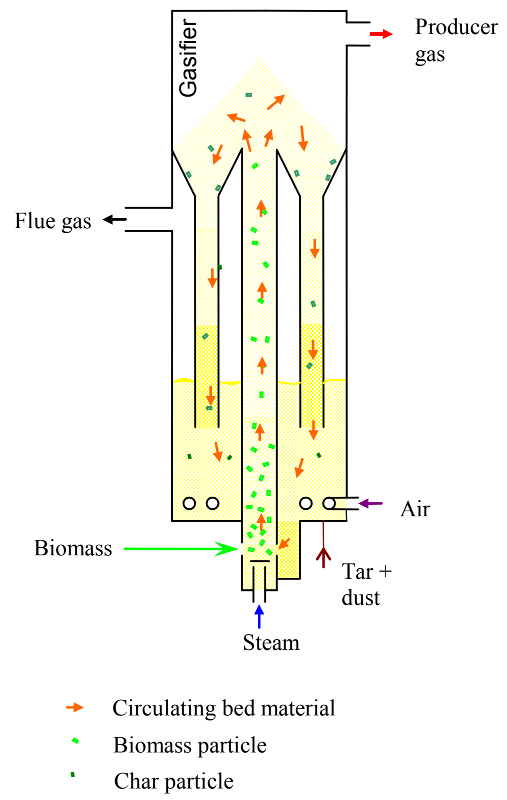

Figure 1: Simplified scheme of MILENA gasifier

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 compounds, which have to be removed before the catalytic conversion of the gas into Bio-SNG. All fluidized bed gasifiers produce gas which contains 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 [2]. 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 given in table I.

Table I: Fuel composition on a.r. basis

		Beech wood chips	Lignite
C	[wt. % a.r.]	45.7	55.0
H	[wt. % a.r.]	5.5	3.9
O	[wt. % a.r.]	38.6	25.1
N	[wt. % a.r.]	0.27	0.61
S	[wt. % a.r.]	0.054	0.260
Cl	[wt. % a.r.]	0.045	0.013
Ash	[wt. % dry]	0.9	3.8
Water	[wt. % a.r.]	9.0	13.4
Volatiles	[wt. dry]	82	49.2

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 LAB-SCALE EXPERIMENTS

3.1 Lab-scale set-up

ECN realized a 30 kWth 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 has been used for approximately 1600 hours in gasification mode.

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.

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 tar that is removed from the gas in the OLGA gas cleaning section is normally recycled to the combustor section of the MILENA reactor. In the lab-scale installation this is simulated by adding methane to the combustor.

3.2 Lab-scale experiments

The lab-scale MILENA installation is mostly used to supply gas for methanation experiments. The installation is fed with beech wood. Olivine (from Austria) is used as bed material. Results for these tests have been presented before [ref. Valencia]. More recent tests with lignite were done to get a first impression if the MILENA technology is suitable to convert wood / lignite mixtures into producer gas. The fuel compositions for the tested fuels are

The process conditions for the tests with 100% wood and a wood / lignite mixture are given in table II. The volatile content of lignite is lower than the volatile content of biomass. It was expected that the conversion of the wood / lignite mixture in the gasifier would be lower than for wood. This will result in more residual char that is combusted in the combustor reactor. More fuel in the combustor will result in an increase in temperature. This is partially compensated by a reduced methane flow and a higher heat loss from the outer wall. The heat loss of the reactor is controlled by the electrical trace heating. The tests confirmed that the conversion of lignite is lower than for wood.

Table II: Process conditions

Primary air combustor	[nl/min]	99	119
Secondary air combustor	[nl/min]	25	25
Methane combustor	[nl/min]	1	0
Beech wood chips	[kg/h]	5.9	2.0
Lignite	[kg/h]	0	2.4
Percentage of lignite	[wt. %]	0	55
Steam on the riser	[kg/h]	2.0	2.0
N_2 on the riser	[nl/min]	1.0	1.0
CO_2 on the feeding screw	[nl/min]	1.0	1.0

The first wood / lignite tests showed that the MILENA gasifier can be used to convert wood / lignite mixtures up to approximately 50% in a producer gas. The measured gas composition is depicted in Figure 2.

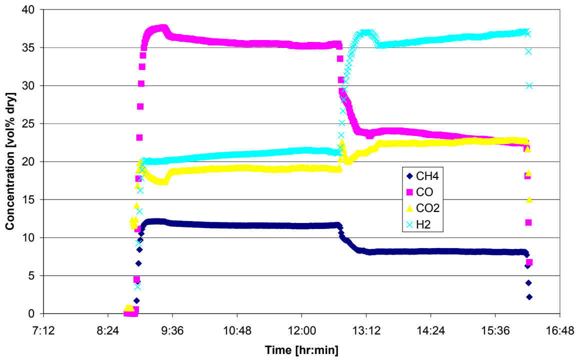

Figure 2: Measured producer gas composition during lignite / wood test.

The first part of the test was done using 100% wood, the second part using the wood / lignite mixture. As can be seen from the figure the H_2 content increases and the CO content decreases. This is probably caused by the CO shift equilibrium reaction. During the wood / lignite mixture test the gas composition is closer to CO shift equilibrium. Table III shows the average measured gas compositions. The measured tar concentration was significantly lower during the test with the wood / lignite mixture compared to 100% wood. A possible explanation is the lower tar production of lignite. Another explanation can be the catalytic behavior of the lignite char in the riser or improved catalytic behavior of the bed material (olivine) due to the presence of lignite (char).

Table III: Measured gas composition

Percentage of lignite	[wt. %]	0	55
CO	[vol% dr.]	37.2	23.3
H_2	[vol% dr.]	21.2	36.2
CO_2	[vol% dr.]	18.9	22.6
CH_4	[vol% dr.]	12.1	8.2
C_2H_2	[vol% dr.]	0.4	0.2
C_2H_4	[vol% dr.]	4.6	2.9
C_2H_6	[vol% dr.]	0.4	0.2
C_6H_6	[Vppm dr.]	8290	6787
C_7H_8	[Vppm dr.]	1332	1009
N_2	[vol% dr.]	4.4	4.4
Class 2	[mg/Nm^3]	4842	1674
Class 3 (excl. toluene)	[mg/Nm^3]	580	241
Class 4 (2 & 3 ring)	[mg/Nm^3]	13801	9157
Class 5 (4 & 5 ring)	[mg/Nm^3]	2666	1745
Unknown	[mg/Nm^3]	8450	3271
Total tar (excl toluene)	[mg/Nm^3]	30340	16088

The results from wood / lignite tests will be presented in more detail during the 2009 Pittsburgh Coal Conference and will be published in the proceedings.

4 PILOT PLANT EXPERIMENTS

4.1 Pilot plant set-up

The MILENA pilot plant was taken into operation in the summer of 2008. The goal for the pilot plant was 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. The lab scale installation was limited to particles of 1 – 3 mm. The lab scale installation was 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.

A simplified scheme of the MILENA pilot installation connected to existing gas coolers, gas cleaning and boiler is given in Figure 3.

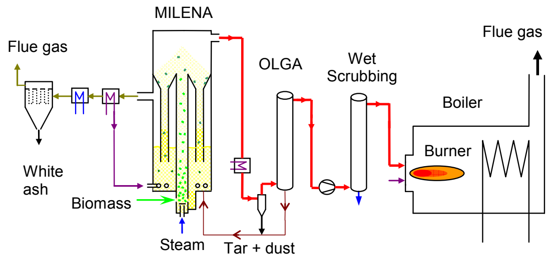

Figure 3: Schematic overview of pilot installation

Producer gas from the MILENA gasifier is cooled from approximately 850°C to 400°C in a tube and shell cooler [5]. 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 returned to the MILENA combustor. The light tars are stripped with air from the OLGA absorption fluid (oil) and are taken up into the combustion air. No additional fuel is required in the combustion section, contrary to some other indirect gasification concepts where significant amounts of gas are needed to operate the combustion reactor. Ammonia, chlorides and water can be removed from the gas by the existing wet cleaning system [6]. A booster increases the pressure of the gas to 70 mbar. This gas pressure was required in the past to use the producer gas as fuel for a gas engine. No gas engine tests are planned for the future, 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. 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 Nm^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 kWth (HHV basis). Because of the higher thermal input and higher efficiency of the MILENA gasifier the thermal input to the boiler increased significantly. Because of the increase in thermal input 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 IV.

Table IV: 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	[Nm^3/h]	174
Tar and BTX to combustor	[kW]	55
HHV gas wet basis excl. tar	[MJ/Nm^3]	13.1
HHV gas dry basis excl. tar	[MJ/Nm^3]	18.0

The tar in the producer gas and some of the benzene and toluene are going to be removed from the gas in the OLGA gas cleaning. The tar, benzene and toluene are going to be used as fuel in the combustor. In the first phase of operation of the pilot plant the recycle of tar will be simulated by adding natural gas to the combustor. Full-scale plants will include tar recycle, which means that no additional fuels are needed in the combustion zone.

4.2 Pilot plant experiments

The pilot plant tests started during the summer of 2008. The gas was directly fired in a gas fired boiler. Several short tests runs were done to check the operational behavior of the installations and to test the different safety measures. Wood pellets were selected as standard fuel, because of easy logistics and stable feeding properties. First (operational) tests were done using olivine as bed material, but it was decided to switch to sand (dp 0.3 mm), because the loss of bed material was relatively high and the make up system for the bed material was not working properly. The composition of the gas was similar to the gas produced in the lab-scale installation when sand was used as bed material. Figure 4 shows the raw measured gas composition. Around 4:00 the installation was taken out of operation shortly, because of tar fouling problems in front of the boiler.

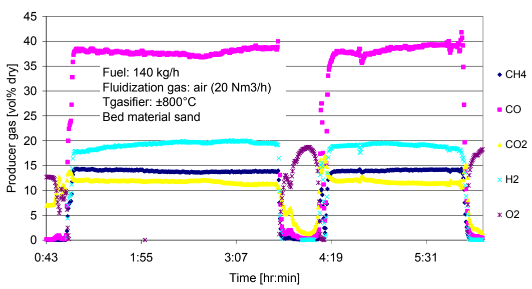

Figure 4: Example of measured gas composition

The tar content of the gas is approximately 40 gram/Nm^3. Sand was used as bed material. This is similar to the lab-scale installation when sand is used. This level of tar will cause problems if the gas temperature drops below approximately 400°C. In the present system the gas is cooled to 400°C, dust is removed in a cyclone and the gas is sent to a boiler. The gas cleaning system was bypassed to reduce the costs of running the installation. The temperature of the gas drops to approximately 250 - 300°C in front of the burner, because of the heat loss of the (long) pipe. Because of this low temperature the tar in the gas condenses and the pressure drop over the burner increases. If the pressure drop is too high the control system shuts the installation down. Tar removal or an increase in gas temperature in front of the burner is required to run the system continuously. The OLGA tar removal system will be available during the next test. The test program will be continued after the summer of 2009.

The following tests are scheduled:

1. Coupling of the OLGA tar removal system, using wood pellets as fuel.
2. Testing different bed material: sand and olivine.
3. Testing of different mechanical configurations to solve friction problems.
4. Duration test using demolition wood A (clean wood)
5. Duration test using demolition wood B (painter wood).

5 FURTHER PLANS

HVC Group and ECN plan to build a 10 MW_{th} MILENA gasifier in combination with OLGA gas cleaning and a gas engine in 2011 in Alkmaar (The Netherlands). HVC Group (situated in Alkmaar, North Holland) is a modern public service waste company. Waste Wood will be used as fuel. The 10 MW_{th} Combined Heat and Power (CHP) demo is considered to be a crucial intermediate step towards commercial SNG plants. The 10 MW_{th} CHP demo however is also considered to be a demonstration of a commercial size CHP unit. The 10 MW_{th} CHP demonstration therefore serves two goals. After a successful CHP demonstration further scale-up to a 50 MW_{th} SNG demonstration unit is foreseen. Figure 5 shows the planned development trajectory.

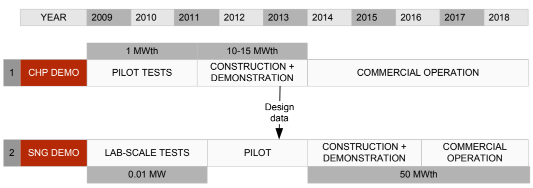

Figure 5: Planned development trajectory

6 CONCLUSIONS

Lab-scale experiments have shown that the MILENA technology is suitable to gasify wood / lignite mixtures. More experiments are required to produce the required relations for conversion versus gasification temperature for different mixtures. Pilot scale tests are required to confirm the results. The first results show a decline in tar concentration when lignite is mixed with wood.

The results from the MILENA pilot plant are according expectations. The gas composition is similar to the lab scale installations. Tar removal is required to run the system continuously. The pilot scale OLGA tar removal unit will be taken into operation in August 2009. Mechanical modifications are scheduled to solve thermal expansion problems.

Modeling results using data from lab-scale and pilot scale experiments have confirmed that an overall net efficiency from (waste) wood to Bio-SNG of 70% is achievable.

The next step in the development of the MILENA gasification technology is the scale-up to 10 MW_{th}. A consortium to realize this demonstration is formed. Basic engineering will start in de second half of 2009. The construction of the plant is scheduled for 2011.

7 ACKNOWLEDGEMENTS

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