Wood to Bio-Methane demonstration project in the Netherlands

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ABSTRACT: The Energy research Centre of the Netherlands (ECN) has developed a biomass gasification technology, called the MILENA technology. The Milena gasification technology has a high cold gas efficiency and high methane yield, making it very suitable for gas engine and turbine applications as well as upgrading of the gas into Bio-Methane. An overall efficiency from biomass to power of over 30% is possible, whereas 70% efficiency is achievable from biomass to gas grid quality methane.

HVC Group (situated in Alkmaar, North Holland) is a modern public service waste company. HVC converts waste streams which cannot be recycled into usable forms of energy. HVC has a 75 MW_{th} waste wood boiler in operation which produces heat and electricity, and an anaerobic digester which converts domestic fruit, vegetable and garden waste into Bio-Methane. HVC expects an important role for Bio-Methane in the future and HVC has decided to join ECN with the development, demonstration and implementation of the MILENA Bio-Methane technology.

Linked to the Bio-Methane demonstration project is the Netherlands Expertise Centre for Biomass Gasification. The MILENA demonstration project and the Gasification Expert Centre are supported by the following companies and organizations: HVC, TAQA, Gasunie, Dahlman, province of North Holland, the Alkmaar municipality and ECN.

In 2010 and 2012 extensive lab-scale and pilot scale tests have been executed by ECN and HVC to proof that the gasification and gas cleaning technology is ready for commercial application. The final step in this test program was a duration test in the 800 kW_{th} MILENA pilot plant coupled to the OLGA tar removal unit. The goal was to show high availability. The result of the test was an availability of the gasifier of 96% and an overall availability (including gas cooling and gas cleaning) of 85%. The results of the duration tests convinced HVC and the other partners that the technology is ready for scale-up.

The results produced in the lab-scale and pilot scale installation were used to design the scaled up version of the MILENA gasifier and were also used to define and optimize the overall wood to Bio-Methane system.

The last two years a lot of effort was spent to form the consortium and arrange the subsidies required for this demonstration project. At the moment Dahlman, licensee of the MILENA and OLGA technology, is doing the detailed engineering of the plant. The final investment decision is anticipated for the summer of 2013, start of construction of the demonstration plant is scheduled for 2014.

Keywords: dual fluidized bed, demonstration, allothermal gasification, biomass conversion, bio-syngas, gasification, methane, synthetic natural gas (SNG).

1 INTRODUCTION

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.

Gasification technology, in combination with gas cleaning and catalytic conversion of the gas offers the possibility to convert a solid biomass into a gas with the same properties as natural gas.

Biomass gasification technology is still under development. A limited number of demonstration plants and commercial plants is in operation. Successes with these first plants have resulted in an increasing interest for biomass gasification. Several biomass gasifiers in combination with gas engines are under construction at the moment. Most of these gasifiers use clean wood as a fuel. The ECN development is focused on also using waste as fuel.

ECN (Energy research Centre of the Netherlands) has developed an indirectly heated (allothermal) biomass gasification process (MILENA), optimized for the production of Bio-Methane, but the gas can also be used in boilers, gas engines, gas turbines or the production of Fischer-Tropsch diesel. The MILENA fluidized bed gasifier is fuel flexible. An extensive test program was done to prove that the MILENA gasifier can handle demolition wood and that the availability of the installation is sufficient for commercial application. The data obtained from duration tests done in the pilot plant in 2010 and 2012 were used to design a 12 MW_{th} demonstration plant that will be constructed in Alkmaar in The Netherlands. A similar plant is under construction in Goteborg, based on the FICFB gasification technology developed by Technical University Vienna.

2 MILENA GASIFICATION TECHNOLOGY

The first design of the MILENA gasifier was made in 1999. The first cold flow, 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. 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 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 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 (or any other gas available including air) is added from below to enable bed material circulation in the bottom of the riser reactor. Hot bed material (typically 925°C sand or olivine of 0.2-0.3 mm) enters the riser from the combustor through a hole in the riser. The bed material heats the biomass to 850°C. The heated biomass particles degasify; they are converted into gas, tar and char. The volume created by the gas from the biomass results in a vertical velocity of approximately 6-7 m/s, creating a “turbulent fluidization” regime in the riser and carrying over of the bed material together with the degasified biomass particles (char). The vertical velocity of the gas is reduced in the settling chamber, causing the larger solids (bed material and char) to separate from the gas and fall down into the downcomer. The producer gas leaves the reactor from the top and is sent to the cooling and gas cleaning section. 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.

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. 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 [1]. 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 or gas turbines.

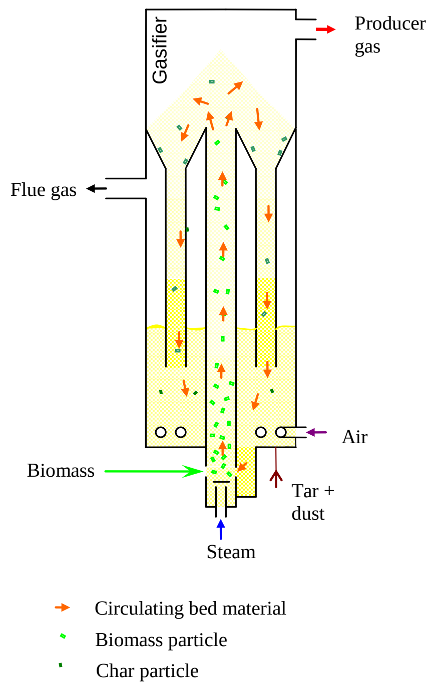

Figure 1: Simplified scheme of MILENA gasifier.

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 25 wt.% moisture are used as fuel. Efficiency can be improved by using low temperature waste heat for biomass drying.

To produce Bio-SNG, 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-Methane is ready for gas grid injection or can be used as transport fuel. If a surplus of H_2 is available (produced from a surplus of renewable electricity) this can be mixed in before the methanation catalysts. By mixing in H_2 the overall conversion of carbon in the gas (present as CO and CO_2) will increase.

3 PILOT PLANT

3.1 Design of pilot plant

The goal for the pilot plant was to realize an installation, which can 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 because of limitations in the feeding system. A simplified scheme of the MILENA installation connected to existing gas coolers, gas cleaning and boiler is given in Figure 2.

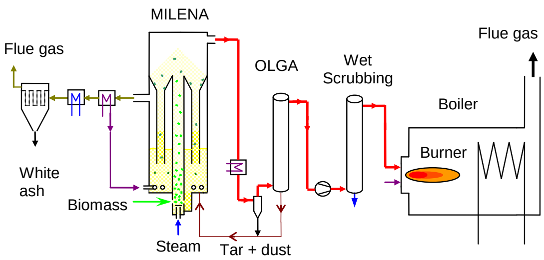

Figure 2: Schematic overview of pilot installation.

Producer gas from the pilot MILENA gasifier is cooled from approximately 850°C to 500°C in a double pipe cooler [2]. 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 commercial size installations. 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 wet cleaning system [3]. A booster increases the pressure of the gas to 70 mbar in the pilot plant. The 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 is combusted in a gas boiler in the pilot plant at ECN.

The flue gas from the MILENA combustor is cooled to 150°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 basic design data for the MILENA gasifier fueled with dry wood pellets is given in Table I. The tar in the producer gas and some of the benzene and toluene are removed from the gas in the OLGA gas cleaning. The tar, benzene and toluene are used as fuel in the combustor.

Table I: 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

3.2 Demolition wood duration tests

A duration test on demolition wood was done in the autumn of 2010 in cooperation with operators from HVC [4].

The demolition wood used was of the so called 'B' quality according to Dutch qualification. This means that it includes painted waste wood and particle board. It must be noted that the composition of the demolition wood varied strongly during the tests, some batches contained large amounts of particle board material and others contained significantly more gypsum board material than average.

In total 243 hours of operation of the entire plant were recorded during the 2010 duration test. The first half of the test was done with clean wood pellets, the second half with demolition wood. During wood pellets operation the MILENA gasifier ran without any problems. During waste wood operation the gasifier had to be shut down twice because of accumulation of glass in the riser. The bed material discharge was increased to prevent accumulation of the large particles. Most of the other shut downs were caused by fouling of the piping that connects the gasifier to the gas cleaning. The distance between the gasifier and gas cleaning is relatively long, because there was no room in the gasifier building to place the gas cleaning. This was the major cause for the clogging of the piping. For commercial plants this should not be an issue, because the gas cleaning is placed next to the gasifier.

The tests showed that the MILENA can gasify waste wood, but the availability of the installation was not sufficient for commercial operation. Therefor it was decided to modify the piping between the gasifier and the gas cleaning and to try to reduce the tar dew-point to improve the availability of the system.

3.3 Duration tests using wood chips

In preparation of the new duration tests several bed material tests were done in the lab-scale and the pilot scale installation to reduce the tar dew point to reduce problems in the piping between the gasifier and the gas cleaning. The lab-scale test results were very promising. Reduction of the heavy tars by a factor of 5 was possible (see Figure 5), so it was decided to do bed material tests at pilot scale as well. One of the pilot scale tests done was the addition of dolomite to the bed, because the catalytic activity towards tar cracking of dolomite is well known. During the pilot scale tests with dolomite as an additive the flue gas cooler got clogged. Because of time and budget constrains it was decided not to continue with adding dolomite to the bed. It was also decided to continue the duration test with Norwegian olivine, because most of the operational experience was gained with this bed material, despite the fact that the catalytic activity towards tar reduction is very low. Fouling problems in the piping were prevented by adding an mechanical cleaning device Figure 3 shows the measured gas composition during the 2012 duration test. Air instead of steam was used as fluidization gas for the riser, this dilutes the gas somewhat. Air was selected because the intended usage of the gas was in gas engines; a small amount of N_2 in the gas is acceptable for gas engines (or gas turbines). When the gas will be used for Bio-Methane production the riser will be fluidized with steam to prevent N_2 dilution. The advantage of using air over steam is the increased overall efficiency, because for the production of steam water needs to be evaporated.

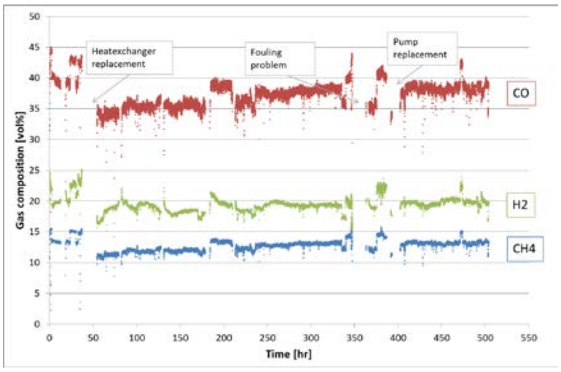

Figure 3: Measured gas composition during 2012 tests campaign (air used as gasification medium).

The tar content of the gas was during this test were very high. The highest measured tar concentration was 73 g/nm^3 of which 8.5 g/nm^3 was class 5 tars. Despite this high tar content fouling of piping was not a problem. The online cleaning system worked very well.

The primary goal of the 2012 duration test was to show that the integrated installation (MILENA gasifier + OLGA tar removal) could be operated with a high availability. Figure 4 summarizes the availability of the complete installation during the 500 hours that operators of ECN and HVC were available to run the installations.

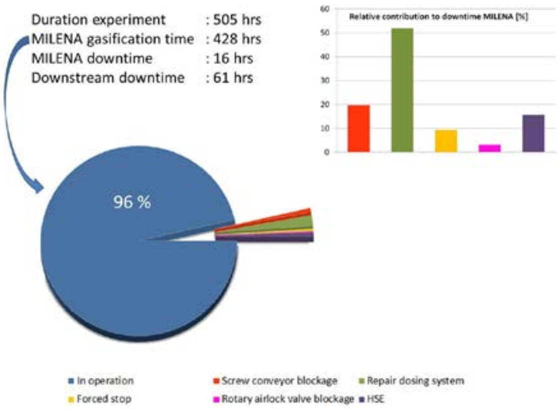

Figure 4: Availability of the MILENA installation

Most stops were related to the feeding system. Most of these problems were fixed within minutes, but some required emptying the complete dosing bunker. The overall availability of the system was 85%. The commercial partners were satisfied with this result.

3.4 Tar control

The clogging problems in the piping and the producer gas cooler are related to the concentration of heavy tars in the producer gas. Lighter tars like naphthalene do not give problems in the cooler, because the wall temperature of the cooler is well above the dew point of the light tars. Experiments with different bed materials and additives have shown that it is possible to lower the concentration of heavy tars in the MILENA producer gas. The catalytic activity of the bed material changes over time, because of changes in the surface composition of the bed material. The use of catalytic bed materials and additives increase the cost of operating a gasification plant, so a continuous monitoring of the tar concentration is required to keep operational costs for bed materials and additives low. ECN developed an online tar measurement device in the past [5], but this device was only able to do measurements after tar reduction devices. It was useful to monitor gas cleaning processes like the OLGA tar removal technology, but can not be used to optimize fluidized bed gasifiers. No online devices are available to measure heavy tar concentrations in raw gas. To overcome this problem a relation was sought that was able to use the continuous measured gas composition to get an indication if the bed material was still catalytically active. The ratio of $CO_2 * H_2 / CO^2$ appeared to give a good indication for the concentration of heavy tars in the MILENA gasification process. Figure 5 depicts the measured class 5 tars and the mentioned gas composition ratio for woody fuels.

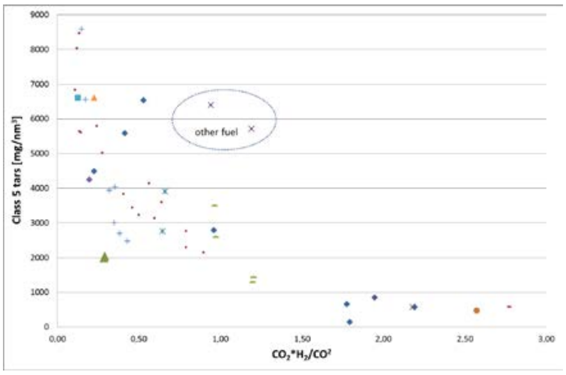

Figure 5: Concentration of heavy tars as function of gas composition ratio for many different test conditions.

4 BIO-METHANE SYSTEM LAYOUT

The overall efficiency from wood (25 wt.% moisture) to bio-methane is expected to be near 70% (LHV basis, including electricity consumption) for commercial size installations based on indirect gasification [6]. Several process layouts are possible, all with their advantages and disadvantages. ECN selected the process layout as shown in Figure 6. The MILENA gasifier and OLGA tar removal unit are operated near atmospheric pressure. After tar removal water is removed from the gas, because this is required for the compressor. The removal of water is undesired because water is required later on in the process. The gas pressure is increased to a few bar. It is expected that the operating pressure of the MILENA gasification technology will be increased to a few bar, so the gas does not need to be compressed anymore and the water can stay in the gas.

A Hydro-DeSulfurization (HDS) catalyst is used to convert organic sulfur compounds (thiophenes) into H_2S, because the removal of organic sulfur compounds is not possible with the foreseen sulfur removal technologies to a sufficiently low level (<< 1 ppm). The HDS reactor is operated above 300°C, so the gas needs to be heated before the catalysts and is cooled again after the HDS unit. Many different technologies are available for the removal of H_2S (and COS). ECN uses ZnO in their lab-scale installations. ZnO will be used as a guard bed after a bulk sulfur removal technology in the demonstration installation. After Sulfur removal a pre-methanation or pre-reforming step is foreseen. In this the catalytic reactor the higher hydrocarbons (e.g. benzene and toluene) are reformed and some of the syngas is converted into methane. The typical operating temperature of the pre-reformer is between 550°C and 600°C. The reform reactions are endothermic, but the methanation reactions are exothermic, this makes the overall reaction adiabatic or slightly exothermic. Before the pre-reformer the gas needs to be heated and after the heat exchanger cooling is required. Some steam is added to the gas to prevent the formation of soot on the catalyst surface. The need for heat exchangers for the HDS and Pre-reform reactors is one of the disadvantages of this system layout.

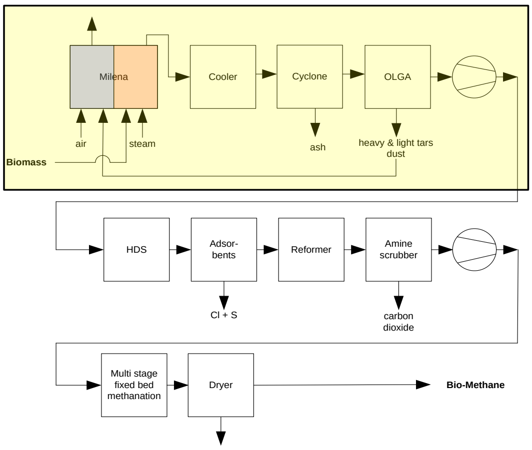

Figure 6: Prefered Bio-Methane system layout.

After the conversion of the higher hydrocarbons an conventional amine scrubbing system can be used to remove approximately 85% of the CO_2 from the gas. The only hydrocarbon that will dissolve in the amine liquid is CH_4, but the solubility of CH_4 in amine liquids is very low al low pressures compared to the alternative CO_2 removal technologies, so the overall CH_4 loss is relatively low. The saturated amine scrubbing liquid is regenerated. The CO_2 and the very low CH_4 concentrations are vented into the atmosphere. The basic idea behind this layout is that the CH_4 emissions of the system should be minimized, because the driver for producing Bio-Methane is the reduction of greenhouse gasses. The contribution of CH_4 to global warming is 25 times more than for CO_2, so methane slip in a Bio-Methane plant should be minimized. The disadvantage of amine scrubbing is the requirement for a significant amount of heat to regenerate the amines, but in the foreseen system this heat (temperature level 130°C) is available. Another benefit of this layout is the reduction in gas volume that needs to be compressed.

After CO_2 and water removal the remaining gas is compressed to the typical operating pressure of commercial methanation catalysts. The methanation reactors are normally placed in series with cooling in between. A gas recycle might be used to limit the temperature in the reactor. The CO_2 removal is tuned in such a way that the remaining CO_2 reacts with the surplus of H_2 in the gas to CH_4 and H_2O. After removal of the produced water the gas is ready for gas grid injection.

One of the possible issues with the reforming and methanation is the formation of soot. To reduce the chances of soot formation the process conditions in the pre-reformer and methanation reactors are chosen such that in theory no soot is produced. Figure 7 shows the CHO diagram for the conditions in the pre-reformer. Steam is added to the gas to keep the operation point below the soot formation lines.

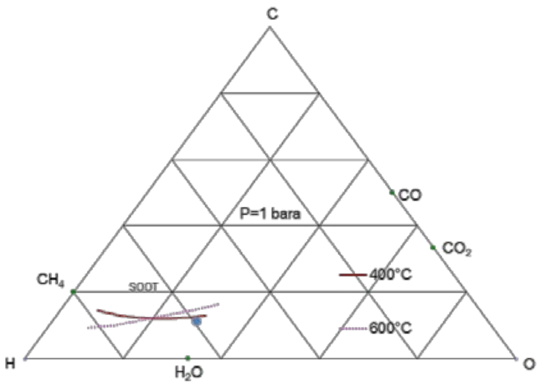

Figure 7: CHO ternary diagram, dot represents pre-reformer conditions.

Figure 8 depicts the operating conditions for the methanation reactor. The operating point is on the line between H_2O and CH_4. This means that there is no need for CO_2 removal anymore after the methanation, only water removal is required.

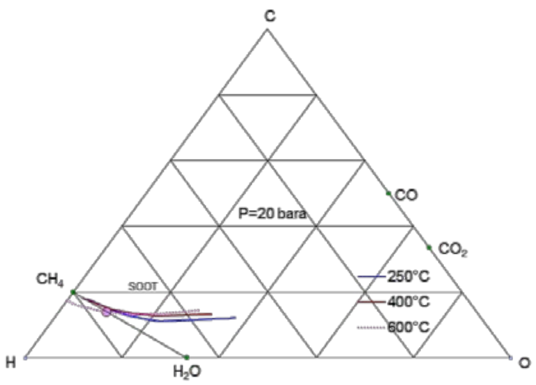

Figure 8: CHO ternary diagram methanation conditions

5 BIOMETHANE DEMONSTRATION PLANT

After a delay of more than two years the engineering of the MILENA demonstration installation was continued in 2013. The delays were caused by changes in the Dutch subsidy regime and an extension of the consortium for the demonstration with Gasunie and other partners. In the present configuration most of the gas will be burned in a gas boiler to produce medium pressure overheated steam. This steam will be used to produce electricity in an existing steam turbine. Figure 9 depicts the demonstration plant.

The MILENA development has attracted attention from other industrial companies as well. Thermax, a large boiler manufacturer from India, has selected the MILENA technology to convert local biomass waste (soya residue) in gas for gas engine application. An 1 MW_e demo plant is scheduled for construction in 2013.

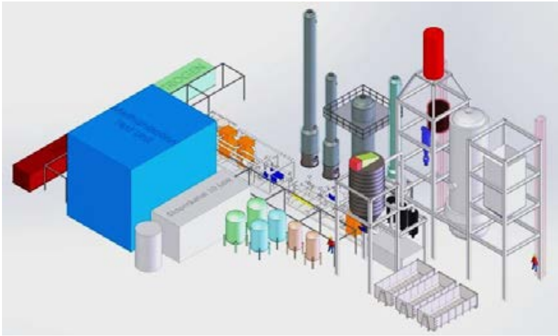

Figure 9: 12 MW_{th} MILENA demonstration plant.

Test done with demolition wood in the pilot plant have resulted in an interest from several companies in the application of MILENA and OLGA for gas production for gas engines. Several commercial offers are under discussion at the moment. In 2013 ECN and Royal Dahlman have signed a license agreement for the MILENA technology. Royal Dahlman already has the license for the OLGA tar removal technology, so they are now able to offer completely integrated solutions for the production of a clean gas from biomass and waste.

Further scale up (to over 100 MW_{th}) is another topic of development. Preliminary designs have shown that this is a viable option. The integrated one vessel concept makes pressurization of the process relatively simple; this is advantageous for further scale up.

5 FUTURE OUTLOOK

ECN is still working on improving biomass gasification systems. Some of the interesting developments that are related to the MILENA demonstration are:

- Production of Bio-LNG (Liquid Natural Gas) by cryogenic separation of CH_4 from the gas.
- Separation of benzene and toluene from the raw gas in combination with the production of Bio-LNG or gaseous Bio-Methane
- Separation of ethylene from the raw gas, possibly in combination with option mentioned above.
- Co-production of Bio-Methane with Fischer-Tropsch diesel.

ECN is already testing some of the mentioned options using the lab-scale and pilot scale MILENA gasifiers. One of the goals of the Biomass Gasification Expert Centre is to use gas from the demonstration plant to do continuous testing of different concepts / catalysts. The advantage of using the demonstration plant is that the gas will be available continuous whereas nowadays only duration tests of a few hundred hours can be done.

6 CONCLUSIONS

The MILENA Bio-Methane development has been ongoing for several years now. The technology has been extensively tested on lab-scale and pilot scale. The duration tests done in 2010 have shown that the system can handle demolition wood. The 2012 duration tests have shown that the reliability and the availability of the technology were increased significantly and have convinced the commercial partners to start a demonstration project.

The overall system from wood to Bio-Methane was optimized with the aim to maximize efficiency and taking into account the practical limitations that resulted from the experimental work that was done using the lab-scale methanation test rig.

It is expected that the construction of the Bio-Methane demonstration tests will start this year. The consortium that was formed to demonstrate this technology has decided to continue this development but is still waiting for the final approval of subsidies. The MILENA Bio-Methane demonstration plant will be part of the Biomass Gasification Expert Centre. Gas produced by the demonstration plant will be made available for testing of other new (catalytic) conversion technologies.

7 ACKNOWLEDGEMENTS

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