Preparations for a 10 MW_{th} Bio-CHP Demonstration based on the MILENA Gasification Technology

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PREPARATIONS FOR A 10 MW_{th} BIO-CHP DEMONSTRATION BASED ON THE MILENA GASIFICATION TECHNOLOGY

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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 application as well as upgrading of the gas into Substitute Natural Gas (SNG).
The HVC Group is a modern public service waste company. HVC converts waste streams which cannot be recycled into usable forms of energy. HVC expects an important role for Bio-SNG and medium size Bio-CHP plants in the future. HVC has decided to join ECN with the development, demonstration and implementation of the MILENA technology for CHP and SNG production.
HVC and ECN are preparing a 10 MW_{th} MILENA gasifier, operated on demolition wood, in combination with OLGA gas cleaning. The cleaned gas will be used in a gas engine to produce heat and electricity. The 10 MW_{th} CHP demo is considered to be a crucial intermediate step towards commercial Bio-SNG plants. The demonstration therefore serves two goals. After a successful CHP demonstration further scale-up to a 50 MW_{th} SNG demonstration unit is foreseen.
After several tests with MILENA (and OLGA) on clean wood fuel, the first tests with the foreseen fuel (demolition wood) were done in 2010 in the MILENA pilot plant. First results show that the behaviour of the realistic sized fuel partners is similar to the previously tested wood pellets. The results are used to do the basic-engineering of the 10 MW_{th} demonstration plant. Start-up of the 10 MW_{th} demonstration plant is scheduled for 2012.

Keywords: allothermal conversion, bio-syngas, gasification, methane, combined heat and power generation (CHP), synthetic natural gas (SNG)

1 INTRODUCTION

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 application or upgrading of the gas into Substitute Natural Gas (SNG).

ECN aims at the development of large scale SNG production and sees the gas engine as an intermediate application necessary for reaching the large scale application. The MILENA Bio-CHP technology will be introduced on a 10 – 30 MW_{th} scale. To achieve both these goals, a waste processing company in the Netherlands (HVC Alkmaar) joined ECN to make the step from pilot scale to demonstration and commercial scale.

The development of this technology started in the laboratory with a 5 kg/h (25 kW_{th}) indirect gasifier. This first MILENA has been operated for about 2000 hours and is actively used for different testing purposes. In 2008 ECN finished the construction of the 800 kW_{th} pilot gasifier MILENA.

The pilot installation is coupled to ECN's technology to remove tar (OLGA) which is a necessary step for the CHP and the SNG applications. The following paper describes the technological achievements made on the pilot scale gasifier in combination with the pilot scale OLGA. Furthermore, it will describe the problems that occurred and the measures taken to overcome this. It will end with an update of the bio-CHP development as it is foreseen in cooperation with the HVC in Alkmaar.

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 [1] 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 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 for 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 or air 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.

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 engines, gas turbines or can be converted into Bio-SNG.

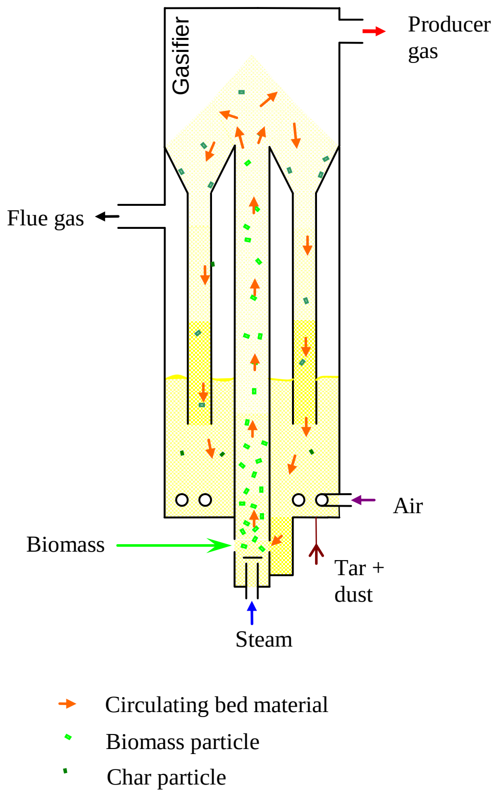

Figure 1: Simplified scheme of MILENA gasifier

2.1 MILENA pilot plant

The 800 kW_{th} MILENA pilot plant connected to the pilot scale OLGA gas cleaning unit is used to test the suitability of the foreseen fuel (demolition wood), to generate data required for the engineering of the 10 MW_{th} demo plant and to acquire the confidence that the technology can operate for a prolonged time.

Figure 2 shows the basic layout of the pilot plant at ECN. The gasifier has a flue gas outlet and a producer gas outlet. The flue gas is cooled. Part of the heat is used to pre-heat the combustion air (typical temperature 340°C). Dust is removed from the flue gas by a conventional bag-house filter. An isokinetic sampling point is installed after the bag-house filter for emission measurements. Samples from the bag-house filter solids outlet are taken on a regular basis to monitor the fly-ash quality. The carbon content of these ashes is always low (<1 wt%), this indicates that the overall fuel conversion is complete.

The producer gas is cooled in double tube cooler that was also used in the past to cool down the producer gas from the BIVKIN installation [3]. The heat is used to pre-heat air. The pre-heated air is used as combustion air in the boiler. The cooled producer gas is sent to the gas cleaning test rig which is located outside the building. A cyclone is used to remove most of the dust (ash, carbon and lost bed material) from the gas.

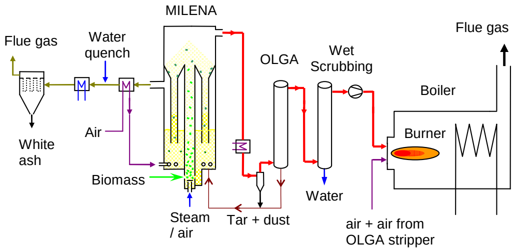

Figure 2: Basic layout of pilot plant

The gas at a temperature between 350 and 400°C containing some small dust particles (typical 1 – 2 g/Nm^3) is cooled and cleaned in the OLGA gas cleaning test rig. Tar and the dust are removed from the gas. The heavy tars, containing some small dust particles are returned to the combustor section of the MILENA. During the first tests the tar-recycle system was not operational and the recycle of heavy tars was simulated by adding natural gas to the bottom of the fluidized bed combustor. The light tars are sent to the boiler.

The producer gas exits the OLGA at a temperature of 80 – 90°C, which is above the water dew point of the gas. The gas is further cooled in the wet scrubbing system down to approximately 35°C (strongly depending on ambient conditions). Most of the water in the gas is condensed out, while avoiding tar condensation as tars are removed to tar dew point levels well below the water dew point. Typical water content of the gas after the wet scrubbing system is 6 vol%.

The pressure of the gas is increased by a booster to approximately 75 mbar. This pressure was required in the past to operate the gas engine that was operated using the gas from the previous BIVKIN gasifier. The gas engine is removed because this is not a topic of research anymore. Gas engines can be operated on producer gas if the calorific value is high enough and the tar dew-point is low enough [4].

The gas is fired in a boiler. The heat is used to heat up water. At the exit of the boiler an isokinetic sampling point is installed for emission measurements.

3 PILOT SCALE EXPERIMENTS

The aim of the tests described here is to generate engineering data for the 10 MW_{th} demonstration plant and to proof that the integrated installation can run without problems using demolition wood B. An important aspect is bed agglomeration. Agglomeration of bed particles causes defluidization of the bed. If the bed is not fluidized anymore the heat transfer between combustor and riser will stop. This will result in an emergency stop.

Table I shows de composition of the fuels tested in the MILENA pilot plant. The composition of the demolition wood is an average from HVC standard composition and two samples of the fraction as used during the experiments. The ash and moisture content varied significantly, this must be taken into account when using these results.

Table I: Fuel composition

		Wood pellets	Demolition wood B
C	[wt.% d.a.f.]	48.2	50.5
H	[wt.% d.a.f.]	6.4	6.2
O	[wt.% d.a.f.]	45.2	41.8
N	[wt.% d.a.f.]	0.130	1.9
S	[wt.% d.a.f.]	0.009	0.114
Cl	[wt.% d.a.f.]	0.012	0.13
Ash	[wt. % dry]	0.3	7.3
Water	[wt. % a.r.]	9	19.3
LHV	[kJ/kg d.a.f]	18536	18902
HHV	[kJ/kg d.a.f]	19929	20227

Figure 3 depicts the demolition wood fraction that was used during the first test with demolition wood in February 2010. Feeding of this type of wood appeared to be problematic, during a 9 hour test run the feeding system blocked twice. The feeding of the wood was quickly restored and the installation was restarted. The fuel pretreatment will be modified to prevent feeding problems during the planned duration tests (100 hours and 1000 hours).

Figure 3: Demolition wood B

The tests were done using Austrian olivine as bed material, because of its catalytic activity towards tar cracking. Tars can cause fouling problems in the producer gas cooler. During the tests no reduction of heat transfer or increase in pressure drop over the cooler was observed. This is an indication that cooler fouling is not a problem.

Table II shows the measured gas composition directly after the MILENA during the demolition wood test campaign. Two different tests were done, one with steam as fluidization gas for the riser and one with air. If the gas is going to be upgraded into Bio-SNG the nitrogen content should be minimized and steam (or CO_2) is the logical choice as fluidization agent of the riser. For application of the gas in a gas engine, the nitrogen content is less relevant and therefore air is the more logical choice, because this saves the heat for the evaporation of the water.

Table II: Measured gas composition after MILENA

Fluidization agent		steam	air
Gasification temp.	[°C]	795	851
CO	[vol% dr.]	31.1	29.7
H_2	[vol% dr.]	26.2	20.5
CO_2	[vol% dr.]	19.9	16.6
CH_4	[vol% dr.]	12.5	10.7
C_2H_2	[vol% dr.]	0.2	0.2
C_2H_4	[vol% dr.]	4.3	3.1
C_2H_6	[vol% dr.]	0.5	0.2
C_6H_6	[Vppm dr.]	7836	8417
C_7H_8	[Vppm dr.]	1037	459
N_2	[vol% dr.]	4.5	19.1
Total tar	[g/Nm^3 dr.]	n.m.	26

During the steam gasification tests the gasification temperature was lower than desired, because the amount of combustion air to the combustor was limited by a high pressure drop over the flue gas cooler. The flue gas cooler is now modified to prevent this problem.

The gas composition is according expectations and is suitable for use in a gas engine after tar removal.
Tar is defined as all the hydrocarbons heavier than toluene. The tar concentration is as expected and is high when it is compared to data reported for the FICFB gasifier in Güssing [5]. The OLGA system can handle this relative high concentration of tar. The removed tars are recycled to the MILENA combustion section where they act as fuel. During the tests this was simulated by adding natural gas instead of tar. This will be changed in the future.

The carbon conversion in the riser / gasifier is an important design parameter for commercial size units.
Carbon conversion is defined as:

$$\frac{C_{producer\_gas} - C_{feed\_gas} - C_{additives}}{C_{fuel}}$$

The carbon in the feed gas can be the CO_2 that sometimes is used for purging the feeding screw. The carbon in additives can come from for example dolomite that is sometimes used to remove sulfur in the reactor or as bed material. The carbon in the tar is included in the producer gas. At typical operation conditions (gasification temperature of 850°C) the expected carbon conversion is around 80%. The remaining carbons is used (and required) as fuel for the combustor. The overall carbon conversion is close to 100%.

Figure 4 shows the carbon conversion in the riser for different tests. The carbon conversion is determined from the component and energy balance over the MILENA. The small symbols represent tests done in the 30 kW$_{th}$ lab-scale installation and the large symbols represent the 800 kW$_{th}$ pilot plant. The tests done in the lab-scale installation were done with relative small beech wood particles (0.7 – 2.5 mm), this explains the higher conversion. As a reference test the same beech wood particles were tested in the pilot plant.

The carbon conversion in the pilot plant is close to the assumed design point for the demonstration plant. In the preliminary design of the demo a recycle of tar to the combustor was assumed. If the carbon conversion is too high, not enough fuel / char is available in the combustor to produce the required heat and the process temperatures will decrease. If the carbon conversion in the riser is too low, an excess of fuel goes into the combustor, this can be compensated by recycling the tar to the riser / gasifier instead of the combustor.

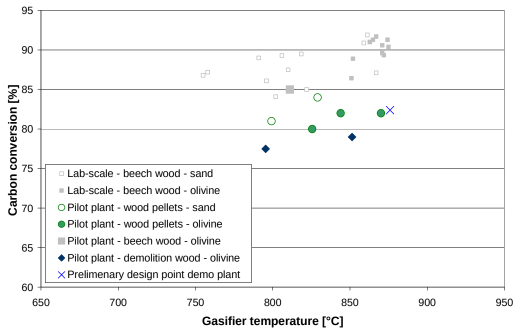

Figure 4: Carbon Conversion in MILENA

The gas composition of a gas produced in a fluidized bed gasifier at 850°C is not at chemical equilibrium, except for the water gas shift equilibrium when a catalytic bed material is used. Empirical relations are used to calculate the hydrocarbon concentrations. The equations used are given in Table III. The relation to predict the CH_4 yield as function of the Equivalence Ratio (ER) was obtained from literature [6]. The other relations are determined from ECN measurements. It must be noticed that the used relation does not include temperature. Measurements have shown that the influence of temperature on methane yield is small at the typical operating window of fluidized bed gasifiers (750 – 880°C).

Table III: Gasifier outlet gas composition relations

Component	Relation
CH_4 (kg kg^{-1} fuel d.a.f.)	0.0873-0.082•ER
C_2H_2 (mol mol^{-1} CH_4)	0.02 • CH_4
C_2H_4 (mol mol^{-1} CH_4)	0.32 • CH_4
C_2H_6 (mol mol^{-1} CH_4)	0.02 • CH_4
C_6H_6 (mol mol^{-1} CH_4)	0.08 • CH_4
C_7H_8 (mol mol^{-1} CH_4)	0.01 • CH_4
NH_3 (mol mol^{-1} N)	0.5 • N in fuel
H_2S (mol mol^{-1} S)	0.9 • S in fuel
COS (mol mol^{-1} S)	0.1 • S in fuel

The relation for CH_4 was verified using the data from the MILENA gasifiers. Figure 5 shows the measured yields of CH_4 as function of Equivalence Ratio (ER). The equivalence ratio is defined as the ratio of the fuel-to-oxidizer ratio to the stoichiometric fuel-to-oxidizer ratio. In principal the ER in an indirect gasifier is close to 0, but can be increased by changing the fluidization gas to the riser from steam to air or by oxygen transport from the combustor into the riser. Some bed materials are oxidized in the combustor and are reduced in the riser. This results in transport of oxygen from the combustor into the riser (chemical looping) and thus in an increased ER in the riser.

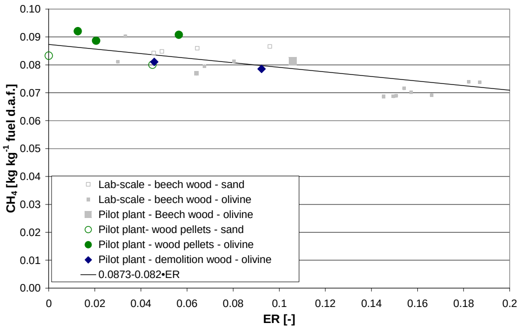

Figure 5: Measured CH_4 yield as function of ER

The measured CH_4 yield is in good conjunction with the empirical relation at the typical gasification conditions in the MILENA.

One of the possible causes for bed agglomeration is melting of glass particles. Glas particles are a very common pollutant in demolition wood. Figure 6 shows a picture of the bottom-ash discharged from the MILENA riser after test with demolition wood. Most of the glass particles were coated with a thin layer of bed material (olivine). The coating prevents sticking of the molten glass particles to each other.

So far, agglomeration of the bed material has not occurred in the lab-scale and pilot-scale MILENA gasifier when (demolition) wood was used as a fuel. Agglomeration only occurred when grass or sewage sludge were tested.

Figure 6: Bottom ash discharge from riser

The screws in the riser bottom ash caused operational problems; they were too big for the ash discharge system. The discharge system is widened to prevent problems during the next duration test.

The pilot scale OLGA gas cleaning connected to the MILENA pilot plant was originally designed for the gas from the 500 kW_{th} CFB gasifier BIVKIN [1] and was slightly modified for the MILENA pilot installation. Despite the fact that the pilot OLGA was designed for lower tar concentrations the measurements show that the removal efficiency for tar is still over 99%, reducing the naphthalene concentration in the gas to below 40 mg/mn³ and the phenol concentration in the gas to even below the detection limit of the applied analytical equipment (< 2.5 mg/m_n^3) [7].

4 MILENA DEMO PLANT

The MILENA demo plant is in the "basic-engineering" phase at the moment (April 2010). The final decision for realization will be taken after a 1000 hour duration test in the MILENA and OLGA pilot scale installation at ECN, using demolition wood as a fuel. The demo plant will be built in Alkmaar next to the waste incinerator and the biomass combustion plant of the HVC group.

Several suppliers of major parts of the MILENA gasifier were consulted to make an accurate cost estimate for a commercial scale MILENA reactor. This cost estimate has shown that a Bio-CHP configuration based on the MILENA technology is economically viable and is adding more value to a fuel like demolition wood than conventional combustion systems do.

Special attention was given to the steel insert which separates the gasification and combustion zone. The steel insert is exposed to high temperatures (approximately 900°C) under oxidizing and reducing conditions. A thermo-mechanical analysis was made using finite element software to check if the structure could support the mechanical stresses for a prolonged period of time. Several suppliers were consulted. Several commercial materials were offered that are expected to be enough corrosion resistant under the operating conditions. The expected lifetime of the insert is more than a year. The mechanical design is made such that replacement of the insert is easy. One of the aims of the demonstration project is to test what lifetime can be achieved.

Figure 7 shows the integrated demo-plant with the fuel bunkers, MILENA gasifier, OLGA gas cleaning, start-up flare, gas engines and containers to test the upgrading of the gas into Bio-SNG.

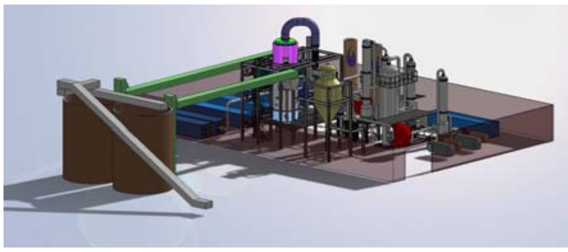

Figure 7: MILENA demo plant

5 OUTLOOK

The interest in the production of Bio-SNG via gasification of (woody) biomass is increasing. This has resulted in an increased interest in the MILENA gasification technology a well.

The preparations for the 10 MW_{th} demonstration plant are on schedule. Construction will start in 2011 if the applications for the necessary subsidies are approved and HVC agrees to enter the next phase. After a successful demonstration, the technology can be commercially applied for Bio-CHP applications. Several commercial parties have expressed interest in licensing the technology. A 50 MW_{th} SNG demonstration plant is scheduled to be started in 2015.

Figure 8 depicts the expected energy balances for different MILENA configuration on commercial scale. The expected overall efficiency is high for the different applications compared to the alternatives.

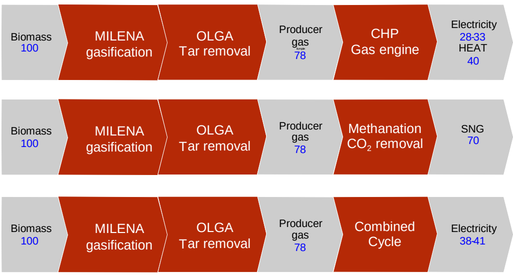

Figure 8: Typical energy balances

Experimental work will focus on testing the catalysts as well as final gas conditioning steps that are required for upgrading the gas into Bio-SNG. Fuel testing in the lab-scale and pilot-scale installation is planned to extend the application of the technology.

6 CONCLUSIONS

The first tests in the pilot plant using demolition wood as fuel have shown that the technology is suitable for this type of fuel. The gas composition was according expectation. The feeding system and the ash discharge system caused operational problems. Better pre-treatment of the fuel is required before the planned duration tests (100 and 1000 hours) can start.

The first tests with the integrated MILENA OLGA system at pilot scale confirmed the suitability of the OLGA technology for the removal of the relative high concentration of tar.

The basic engineering of the 10 MW_{th} demonstration plant is nearly finished. Cost estimations are now more accurate and have shown that the combination of the MILENA gasifier and OLGA gas cleaning is an attractive configuration to produce heat and electricity in a gas engine.

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