Waste wood fueled gasification demonstration project

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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 has a high cold gas efficiency and high methane yield, making it very suitable for gas engine application. Overall electrical efficiency of small scale installations (1 – 10 MW_e) can be over 35%, using gas engines in combination with an Organic Rankine Cycle (ORC) and a biomass dryer, this is significantly higher than the efficiencies that can be achieved with steam cycles at this scale and at least competitive with other gasification concepts.

HVC is a modern and innovative waste and energy company. HVC converts waste streams which cannot be recycled into usable forms of energy. HVC has a large waste wood boiler of almost 30 MW_e in operation. HVC has decided to join ECN with the development, demonstration and implementation of the MILENA Bio-CHP technology. HVC and ECN plan to build a 11.6 MW_{th} MILENA gasifier in combination with OLGA gas cleaning. The installation will be located in Alkmaar (the Netherlands).

Originally is was the intention to use the gas in a gas engine and to produce green electricity and heat. Due to changing subsidies in the Netherlands the gas will now be upgraded to natural gas quality, which can be injected in the gas grid and will be sold as green gas. In other countries the subsidies to produce green heat and green electricity are still attractive. Several projects using the MILENA and OLGA technology in combination with gas engines are in the initial phase of development. The typical scales vary between 1 and 4 MW_e.

The basic engineering of the 11.6 MW_{th} MILENA + OLGA demo plant was executed by Dahlman and ECN in 2010. Dahlman (www.dahlman.nl) is the supplier of the OLGA gas cleaning technology. Wood will be used as fuel. An extensive test program using demolition wood as fuel was done in the ECN pilot plant in order to generate the required engineering data. The project was delayed because of changes in the Dutch subsidies for green heat, electricity and gas. A new application for subsidy on green gas will be filed at the end of 2011. Start of construction of the 11.6 MW_{th} demonstration plant producing green gas is scheduled for 2012.

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

INTRODUCTION

Energy is one of the essential ingredients of modern society. Nowadays energy comes for the greater part from fossil fuels like oil, natural gas and coal. The proven fossil oil and natural gas reserves are declining in North America and Europe [1]. According to a study of the Energy Research Centre of the Netherlands (ECN) the global production of oil might decline within 30 years [2]. According the International Energy Agency (IEA) the consumption of primary energy is expected to increase by 1.6% per year. By 2030 consumption is expected to have risen by just over 45% compared to 2006 [3]. On top of the problem of securing the supply, the combustion of fossil fuels produces CO_2, which contributes to global warming. CO_2 emissions from fossil fuels can to some extent be countered by sequestration of CO_2. This CO_2 sequestration, however, lowers overall efficiency significantly, resulting in a higher consumption of fossil fuels per unit of energy delivered.

Biomass energy is expected to make a major contribution to the replacement of fossil fuels. The future world-wide available amount of biomass for energy is estimated to be 200 to 500 EJ per year by 2050, based on an evaluation of availability studies [4]. World-wide oil consumption was 161 EJ (82.5 million barrels of oil per day) in 2005 [1], so the potential of biomass energy is enormous.

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. Biomass can be converted in a combustible gas via gasification. This gas can be used to generate electricity or can be upgraded into other valuable biofuels like Bio-Substitute Natural Gas (Bio-SNG), Fischer Tropsch Diesel, etc..

National governments are promoting the production of renewable electricity by subsidies. The market price (including subsidy) of renewable electricity can be as high as 175 €/MWh_e [5]. This makes the development of highly efficiency Biomass power plants very attractive. Gas engines are to date the most efficient prime movers to produce heat and electricity at relatively small scale (<10 MW_e).

ECN realized a 30 kW_{th} biomass input lab-scale MILENA gasifier in 2004. Several successful duration tests were done. The results of these tests were so promising that it was decided to build an 800 kW_{th} MILENA pilot plant gasifier. The pilot scale gasifier is connected to the OLGA gas cleaning PDU. The gas from the OLGA gas cleaning is clean enough to be used in a gas engine. This was demonstrated on pilot scale for 700 hours in 2006 using a Circulating Fluidized bed Gasifier [6].

BIOMASS GASIFICATION

Gasification processes have been in use since the 1800s. The first application was the production of town gas from coal. From the 1920s gasification was used to produce synthetic chemicals. Most well known is the production of Fischer-Tropsch oil out of synthesis gas in Germany to run the military machinery during the Second World War and, more recently in South Africa.

Nowadays, commercial coal gasifiers are in operation on a scale over 1 GW_{th} [7]. The number of gasifiers based on biomass as a fuel is still limited. The technology of gasification to liquid and gaseous fuels on the basis of biomass as feedstock will get a new boost as it opens the road to produce a green alternative to fossil fuel based energy carriers.

The term gasification is used for processes that convert solid or liquid fuels into a combustible gas at high temperature. The heat required for the heating of the fuel and to energize the endothermic gasification reactions is supplied by the combustion of part of the fuel (direct gasification) or is supplied from external source (Indirect or Allothermal) gasification.

Different gasification technologies for biomass are under development. ECN selected indirect fluidized bed gasification, because this technology is up-scalable, has a high efficiency and is fuel flexible. The ECN technology is named the MILENA process. The combustion and gasification processes are separated, this has the advantage that the producer gas is not diluted with nitrogen, so the heating value of the producer gas is relatively high. The waste streams (tar and char) are used as fuel in the combustor to generate the heat for the endothermic gasification processes.

MILENA GASIFICATION TECHNOLOGY

The MILENA gasifier [8] 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 the figure represent the circulating bed material. The processes in the gasification section will be explained first.

Biomass (e.g. wood) is fed into the riser. A small amount of superheated steam is added from below. Hot bed material (typically 925°C sand) enters the riser from the combustor through a hole in the riser (opposite and just above 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, tar and dust in the combustor.

The flue gas leaving the MILENA installation is cooled down to approximately 100°C and is cleaned in a bag house filter. If clean wood is used as a fuel no additional flue gas cleaning is required.

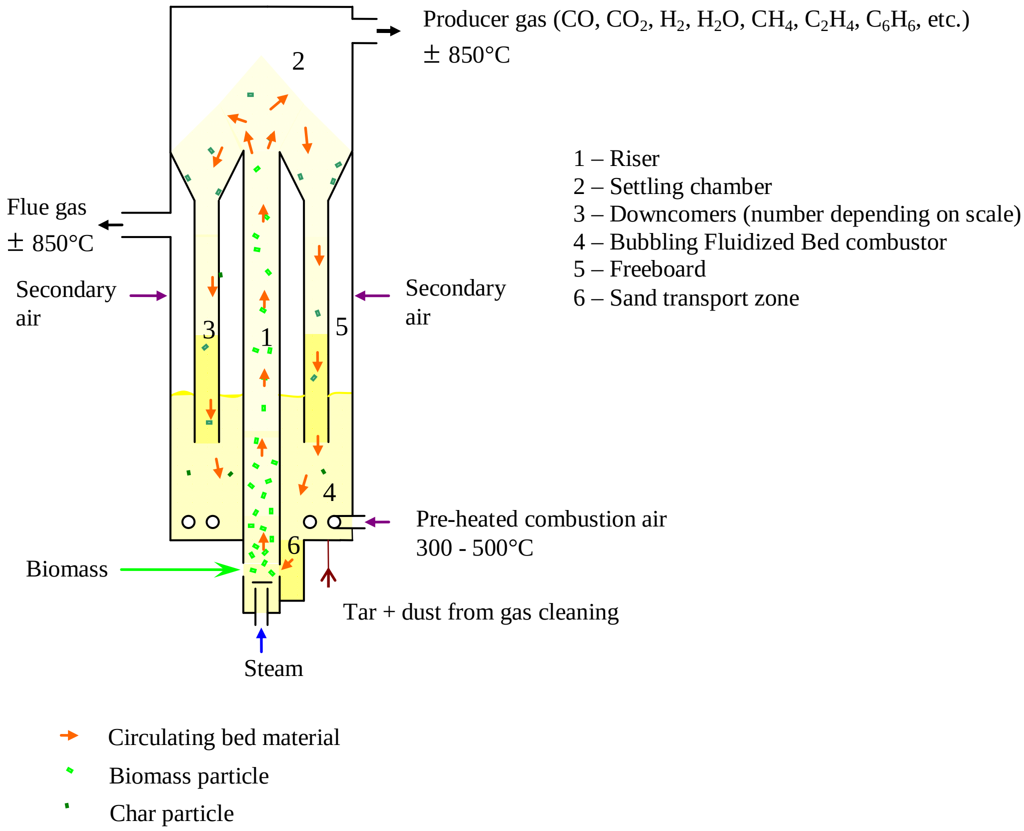

Figure 1: Simplified scheme of MILENA gasifier.

The hot producer gas from the gasifier contains several contaminants such as dust, tar, chloride and sulfur, which have to be removed or lowered in concentration before the gas can be used. All fluidized bed gasifiers produce gas which contains some tar. Tar compounds condense when the gas is cooled, which makes the gas very difficult to handle, especially in combination with dust. The producer gas is cooled in a heat exchanger, designed to treat gas which contains tar and dust. The heat is used to pre-heat combustion air. Tar and dust are removed from the gas in the OLGA gas cleaning section [9]. 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.

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.

BIO-CHP CONFIGURATION

Figure 2 shows the basic layout of a MILENA gas engine configuration. The biomass is converted into producer gas in the gasifier. After cooling and partial dust removal by a cyclone, the tars and the remaining dust are removed in the OLGA gas cleaning. The tar is recycled to the combustor section of the MILENA were it acts as fuel. A wet scrubbing system is used to remove most of the water, chloride and ammonia from the gas. The cleaned gas can be used in the gas engine to produce heat and electricity.

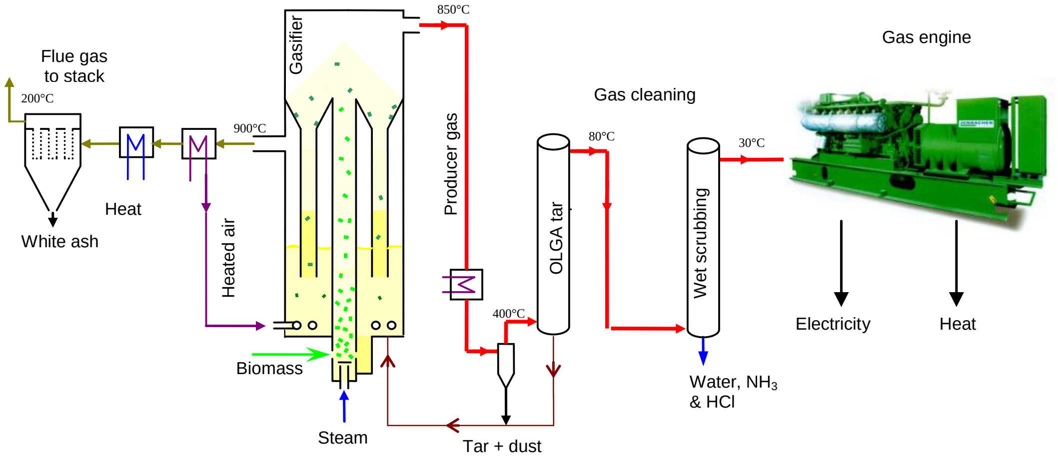

Figure 2: Basic layout of MILENA Bio-CHP plant.

The electrical efficiency of Bio-CHP's using gasification technology can vary significantly. The efficiency is strongly influenced by the type of biomass, water content of the biomass, scale of the installation, type of gasifier, type of gas engine, level of integration and emission limits. Figure 3 shows the calculated net electrical efficiencies for MILENA based Bio-CHP's. The fuel is demolition wood with 20% moisture. The scale is based on the selection of two 2 MW_e gas engines. Residual heat is used for district heating.

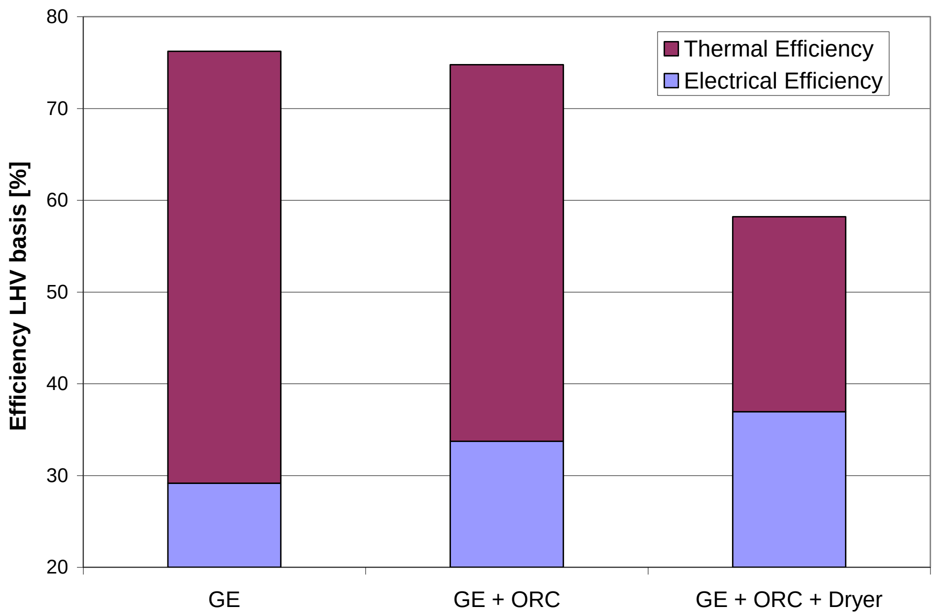

Figure 3: Calculated efficiencies of MILENA Bio-CHP configurations; GE: Gas Engine, ORC: Organic Rankine Cycle.

The left column shows the efficiency assuming the producer gas is fired in a gas engine (GE). Adding an Organic Rankine Cycle (ORC) increases the electrical efficiency significantly. A further increase can be achieved by integrating a biomass dryer. The right column shows the calculated efficiencies assuming wood with 40% moisture is dried to 20%. The MILENA gas engine (+ORC) combinations offers a significantly higher efficiency than combustion based processes at a typical scale of 3 – 10 MW_e. For large scale applications CHP applications a gas turbine in combination with a steam cycle needs to replace the gas engines, to further increase overall efficiency and reduce specific investment costs.

PILOT SCALE TESTING

Figure 4 shows the MILENA and OLGA pilot plant which was used to test fuel that was foreseen for the 11.6 MW_{th} demo plant in Alkmaar.

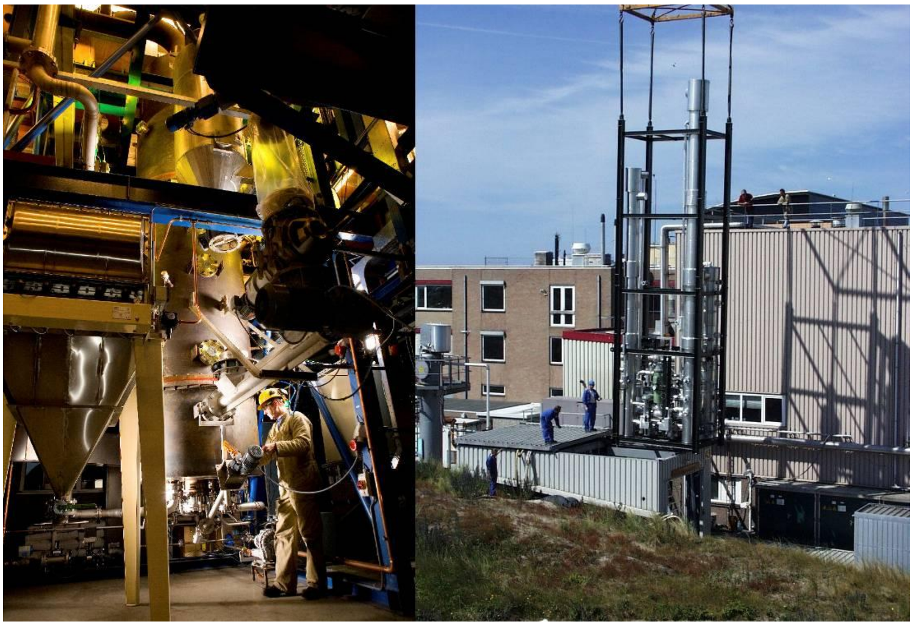

Figure 4: Pilot-scale MILENA gasifier (left) and installation of the OLGA pilot-scale gas cleaning (right).

Figure 5 shows a photo of the demolition wood fraction that was used during the tests. The used fraction is relatively small, because of limitations in the used feeding system. The fraction was sieved from a larger fraction, the sieving resulted in an accumulation of glass particles and stones in the fuel (typically 3 wt%), which ended up in the reactor. The ash discharge system was adapted to minimize accumulation of glass in the reactor. The demolition wood used was of the so called 'B' quality. 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.

Figure 5: Demolition wood B as tested in the MILENA pilot plant.

Table 1 shows the measured compositions of the different wood types that were tested in the MILENA pilot plant.

Table 1: Fuel compositions; ar: as received, daf: dry and ash-free basis.

	Clean wood	Demolition wood B
Moisture [wt.% a.r.]	10.1	19.0
Ash [wt.% d.b.]	1.0	2.7
C [wt.% d.a.f.]	49.2	50.2
H [wt.% d.a.f.]	6.1	6.1
O [wt.% d.a.f.]	44.5	41.6
N [wt.% d.a.f.]	0.2	1.9
S [wt.% d.a.f.]	0.017	0.10
Cl [wt.% d.a.f.]	0.005	0.12
LHV [MJ kg^{-1} d.a.f.]	18.2	18.9
HHV [MJ kg^{-1} d.a.f.]	19.5	20.2

In total 243 hours of operation of the entire plant were recorded during the 2010 duration test. Most of the required shutdowns 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.

Table 2 shows the measured gas compositions. The high nitrogen concentration in the gas during the demolition wood was caused by a relative high amount of fluidization air which was used during this test. This was done to minimize the wood throughput, because the wood storage capacity at the ECN site was limited. In principal the nitrogen content of the gas is similar to what was measured during the clean wood tests, where fluidization was achieved by adding steam.

Table 2: Raw gas compositions

Fuel		Clean wood	Demolition wood
Fluidization gas		Steam	Air
CO	[vol% dr.]	40.9	29.1
H_2	[vol% dr.]	25.5	17.6
CO_2	[vol% dr.]	11.7	13.1
Ar	[vol% dr.]	0.0	0.4
CH_4	[vol% dr.]	15.7	10.0
C_2H_2	[vol% dr.]	0.3	0.3
C_2H_4	[vol% dr.]	4.7	3.1
C_2H_6	[vol% dr.]	0.3	0.2
C_6H_6	[vol% dr.]	1.1	n.m.
C_7H_8	[vol% dr.]	0.04	n.m.
N_2 (measured)	[vol% dr.]	1.5	26.8

The tar concentration after the gas cleaning was low enough for gas engine application. Most of the sulfur in the biomass ends up in the producer gas. If additional sulfur removal is required depends on the local emission limits. The residual ash is completely white / grey. This indicates that there is no unburned carbon left in the ash, the fuel conversion is almost 100%.

CONCLUSIONS

Small to medium scale electricity production using the MILENA gasifier in combination with a gas engine is an attractive option, because electrical efficiency is relatively high and most of the residual heat can be used. Overall electrical efficiency of small scale installations (1 – 10 MW_e) can be over 35%, using gas engines in combination with an Organic Rankine Cycle (ORC) and a biomass dryer, this is significantly higher than the efficiencies that can be achieved with steam cycles at this scale.

Tests done in the 800 kW_{th} (150 kg/h) pilot plant showed that demolition wood is a suitable fuel, most alternative gasification technologies cannot handle polluted demolition wood. Accumulation of glass particles, that are present in the fuel, should be prevented by discharging the bottom ash. The OLGA tar removal technology is able to remove the tars making the gas suitable for (turbocharged) gas engine application. The fuel conversion is over 99%, this is significantly higher than for most biomass gasifiers. The complete fuel conversion benefits the efficiency.

OUTLOOK

The basic engineering of the 11.6 MW_{th} demonstration plant was finished in 2010. 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. Investment cost for a complete plant is around 4000 €/kW_e. The project was delayed because of changes in the Dutch subsidies for green heat, electricity and gas. A new application for subsidy on green gas will be filed by HVC at the end of 2011. Start of construction of the 11.6 MW_{th} demonstration plant producing green gas is scheduled for 2012.

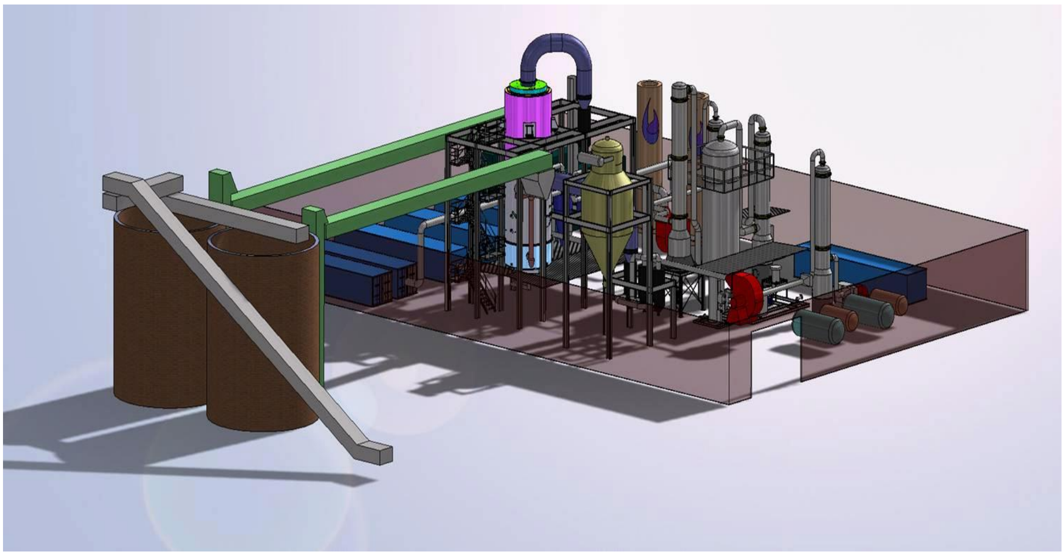

Figure 6: MILENA 11.6 MWth demo plant

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 in gas for gas engine application. An 1 MW_e demo plant is scheduled for construction in 2012.

Further scale up (to over 100 MW_{th}) is another topic of development. The first preliminary design 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.

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