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C.M. van der Meijden
H. Veringa
B.J. Vreugdenhil
A. van der Drift
R.W.R. Zwart
R. Smit

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Christiaan van der Meijden[1*]

Hubert Veringa[2], Berend Vreugdenhil[1], Bram van der Drift[1], Robin Zwart[1] & Ruben Smit[1]

1. Energy research Centre of the Netherlands (ECN), P.O. Box 1, 1755 ZG Petten, The Netherlands
2. Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, the Netherlands
[*] Corresponding author: Phone: +31 224-564582, Fax: +31 224-568487, E-mail: vandermeijden@ecn.nl

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1 Introduction

The production of Methane from biomass is an attractive method to replace declining fossil natural gas reserves. Methane produced from biomass is referred to as Bio-Methane, Green Gas, Bio-Substitute Natural Gas (Bio-SNG) or Bio-CNG when it is used as a transport fuel. The composition of Bio-Methane is similar to conventional Natural Gas, making replacement of Natural Gas by Bio-Methane straightforward.

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, based on an evaluation of availability studies [1]. Word wide natural gas consumption was approximately 100 EJ or 2750 billion cubic meters (bcm) in 2005 [2].

Biomass is considered a CO_2 neutral fuel, as the amount of CO_2 released on burning biomass equals the uptake of CO_2 from the atmosphere during growth of the biomass. Fuels like hydrogen, methane, FT diesel and methanol produced from biomass have the potential to become a CO_2 negative fuel, because part of the biomass carbon is separated as CO_2 in a concentrated stream during the production process. If this pure CO_2 stream is sequestrated, these fuels can become even CO_2 negative. This might be an attractive option for reducing the level of greenhouse gasses in the atmosphere. Figure 1.1 shows the CO_2 balance for Natural gas and Bio-methane produced by gasification of woody biomass.

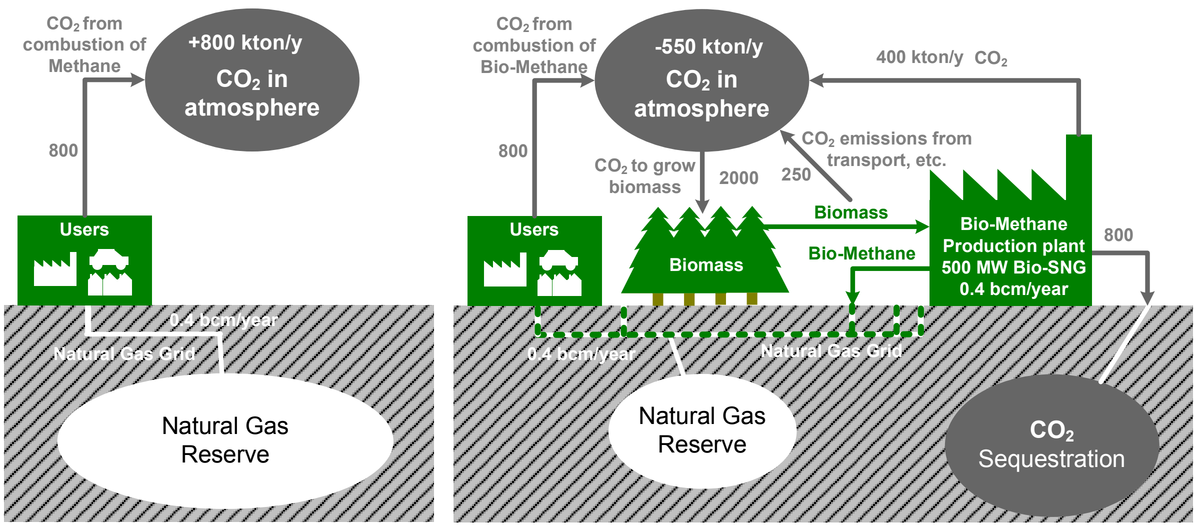

Figure 1.1: CO_2 balance for Natural gas and Bio-Methane produced from woody biomass

As can be seen from the figure the CO_2 emissions from 0.4 billion cubic meters (bcm) of natural gas (assuming 100% CH_4) per year are 800 kton/year if conventional Natural Gas of fossil origin is used. These figures exclude emissions from transport / compression of natural gas. If conventional natural gas is replaced by Bio-Methane produced by gasification of woody biomass, the CO_2 emissions would drop to 250 kton/year. If the pure CO_2 stream that becomes available during the production process is not vented into the atmosphere but sequestrated in an empty gas field, the net CO_2 emissions become negative (-550 kton/year).

The use of biomass for the production of energy is controversial for several reasons. Corn is used on a large scale to produce ethanol to replace fossil gasoline; this resulted in the fuel versus food discussion. Palm oil is used to produce biodiesel. Large areas of rain forest have been burned or taken down in Malaysia to create space for palm oil production. On top of this, some production processes for Bio-fuels require a large (fossil) energy input to upgrade the fuel to an acceptable quality. A well know example is the distillation of the water ethanol mixture to produce fuel quality ethanol. Some fast growing biomasses require nitrogen fertilizers, which are normally produced from natural gas. This has a negative effect on the overall CO_2 balance of the Bio-fuel. The fertilizer can also release greenhouse gasses. To deal with these issues Sustainability Criteria were introduced. These criteria include topics like the greenhouse gas balance, competition with food, biodiversity and local environmental issues. Woody biomass performs very well on these criteria, especially when the wood is converted into a low carbon fuel like methane.

2 Production of Bio-Methane

The production of Bio-Methane via digestion (upgrading of biogas) has been developed and is implemented (mainly) in small-scale installations. The limited amount of suitable digestible feed stock (e.g. manure and food residues) demands for development of new technologies which can convert a wider range of biomass, like wood residue, into Bio-Methane. Gasification is such a route that can convert a wide range of (ligno-cellulosic) biomass into methane.

The Energy research Centre of the Netherlands (ECN) is developing an indirectly heated (allothermal) biomass gasifier (MILENA), optimized for the production of Bio-Methane. The work done at ECN focuses on the development of the MILENA gasification technology for large scale production of gas that can be upgraded into Bio-Methane. The ECN MILENA technology can convert a broad range of biomass fuels and lignite into gas. ECN also develops and tests the required gas cleaning equipment. The gas from the final gas cleaning step can directly be upgraded into CH_4 by conventional and commercially available methanation catalysts. The overall Bio-Methane production plant includes the following production steps:

1) A gasifier where solid biomass is converted into a producer gas;

2) Gas cooling and tar removal;

3) Gas cleaning where the pollutants are removed from the producer gas;

4) Catalytic conversion of producer gas into CH_4, CO_2 and H_2O;

5) An upgrading step where water and CO_2 are removed and the gas is compressed.

The gasifier is an Indirect or Allothermal gasifier (the ECN MILENA gasifier, see www.milenatechnology.com). The basis of the technology development was the experience gained by ECN during construction and operation of Bubbling and Circulating Fluidized Bed gasifiers at both lab-scale and commercial scale on a wide range of fuels. The Circulating Fluidized Bed technology is now commercially available from HoSt (www.host.nl). Tar removal is performed with the OLGA technology (www.olgatechnology.com) developed by ECN [3]. The technology is commercially available from Dahlman (www.dahlman.nl). The chloride and sulfur removal steps are commercially available processes. The catalytic conversion and gas upgrading steps can use commercial processes as well. The final steps can also be executed partly in reversed order. The integrated process is schematically shown in figure 2.1.

The gasifier contains separate sections for gasification and combustion. The gasification section consists of three parts: riser, settling chamber and downcomer. The combustion section contains only one part, the combustor. The arrows in the gasifier figure represent the circulating bed material. The processes in the gasification section will be explained first.

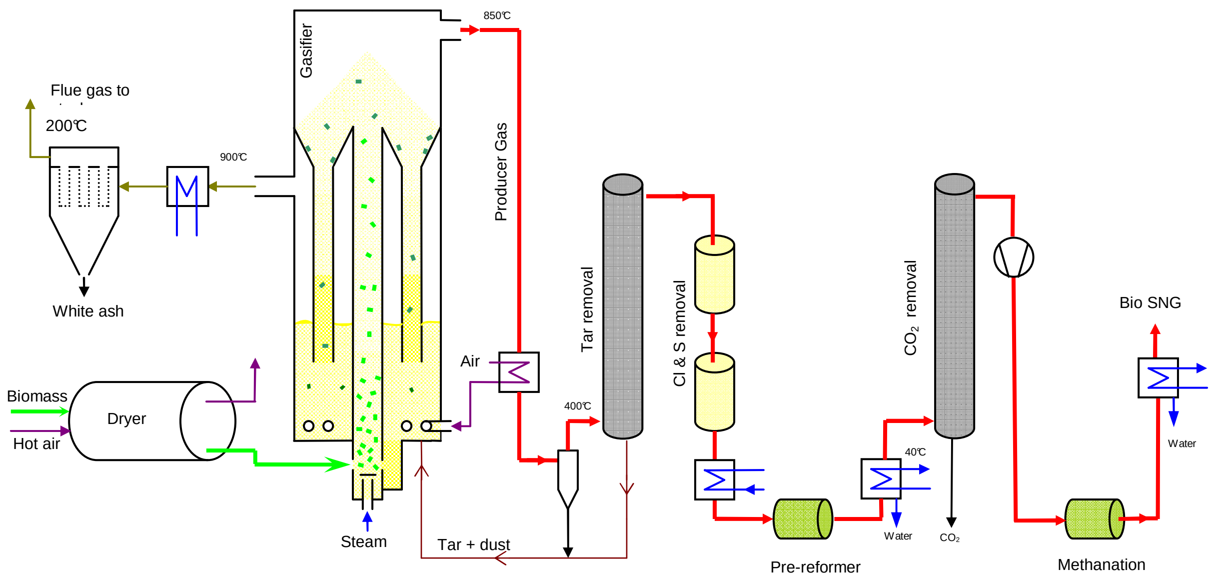

Figure 2.1 : Simplified scheme of MILENA Bio-Methane configuration

Biomass (e.g. wood) is fed into the riser. A small amount of superheated steam is also added to the riser. Hot bed material (typically 925℃ sand or ol ivine of 0.2 – 0.3 mm) enters the riser from the combustor through a hole in the riser (opposite of biomass feeding point). The bed material heats the biomass to 850℃. The heated biomass particles degasify; they are partially converted into gas. 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 settling chamber reduces the vertical velocity of the gas causing the larger solids (bed material and char) to separate from the gas and to fall down into the downcomer. The producer gas leaves the reactor from the top and is sent to the cooling and gas cleaning section. The 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 brought to the combustor. Char, tar and dust are burned with air to heat the bed material to approximately 925℃. 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 necessary for the gasification process is produced by the combustion of char, tar and dust in the combustor.

The hot producer gas from the gasifier contains several contaminants such as dust, tar, chloride and sulphur, which have to be removed before the catalytic conversion of the gas into Bio-Methane. All fluidized bed gasifiers produce gas which contains some tar. Tar compounds get sticky 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. 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, is catalytically converted into a mixture of CH_4, CO_2, H_2O and some residual H2. Commercial techniques, like the Selexol process, can be applied to remove CO_2 and H_2O. The compressed final product can be used as transport fuel in Natural Gas Vehicles or, eventually, can be injected into the gas grid.

The foreseen minimum scale for a commercial Bio-Methane production facility is between 50 and 500 MW_{th} biomass input or between 0.04 and 0.4 bcm (billion cubic metres) a year of Bio-Methane production. Therefore, the aim of the development is a technology that is scaleable to over 100 MW, while producing Bio-Methane with a high net efficiency. The goal is to reach at least 70% efficiency.

3 Results

ECN produced the first Bio-Methane in 2004, using a conventional fluidized bed gasifier. 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 duration 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 directly connected to a boiler to combust the produced gas. In the next phase the pilot scale gas cleaning will be connected to the gasifier in order to produce a clean gas.

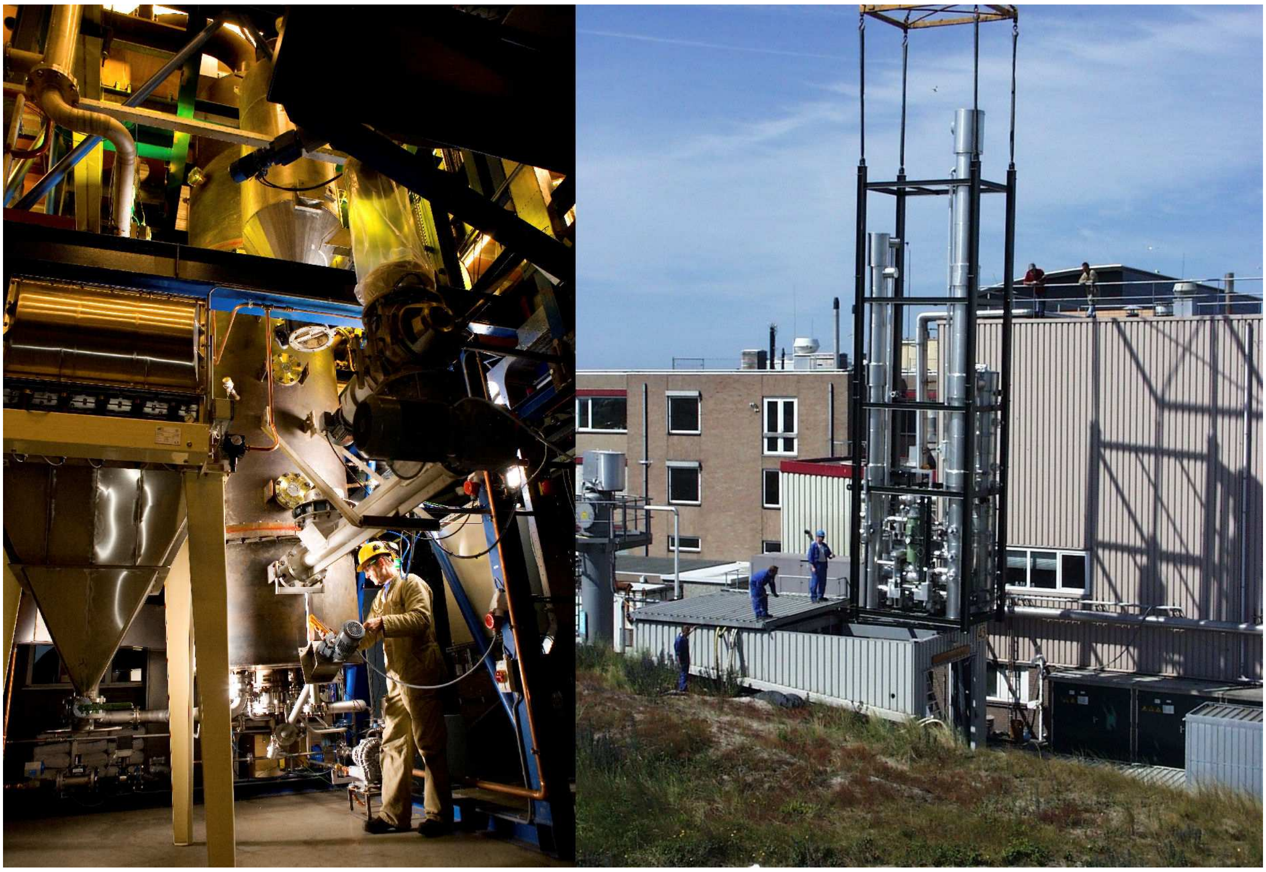

Figure 3.1: MILENA pilot scale gasifier and OLGA pilot scale gas cleaning

The results of the lab-scale and pilot scale experiments were used to verify and optimize the gasification / SNG models. The models were used for the pre-design of commercial Bio-Methane units. The calculated overall net efficiency of the process from wood (25% moisture) to Bio-Methane is approximately 70% (Lower Heating Value basis). A popular alternative Bio-Fuel is Fischer Tropsch Diesel produced from syngas coming from high temperature oxygen blown Entrained Flow gasifiers. An average overall net efficiency from biomass to Fischer Tropsch Diesel below 50% is reported [4]. Entrained Flow gasification technology for biomass is not a commercially available technology, because characteristics of biomass fuels differ to much from coal.

Table 1 shows the calculated gas compositions when (demolition) wood with 25% moisture is converted into producer gas and the producer gas is catalytically converted into Bio-Methane.

Table 1: Expected gas compositions and net heating values (LHV) of MILENA producer gas (after tar removal) and Bio-CNG versus those of Dutch standard natural gas (Slochteren)

		Producer gas	Bio-Methane	Slochteren
CO	[vol%]	17.1	0.0	0.0
H_2	[vol%]	19.3	4.2	0.0
CO_2	[vol%]	12.9	1.7	0.9
H_2O	[vol%]	36.6	0.0	0.0
CH_4	[vol%]	9.0	90.1	84.8
N_2 + Ar	[vol%]	1.0	3.8	14.3
C_2H_y	[vol%]	3.4	0.0	2.9
C_3H_8 C_4H_{10}	[vol%]	0.0	0.0	0.6
C_6H_6 + C_7H_8	[vol%]	0.6	0.0	0.0
LHV	[MJ/m_n^3]	10.4	32.8	31.7

The pre-design was used for an economical evaluation of the Bio-Methane production process. As with almost all bio-energy processes costs are mainly determined by the biomass costs, in particular at larger scales [5]. Therefore SNG production costs are calculated for biomass prices of 0 and 2 €/GJ_{th} (e.g. locally available biomass) as well as of 4 and 6 €/GJ_{th} (e.g. biomass delivered at the gate of larger power plants). Figure 3.2 shows the calculated productions costs. A 1000 MW_{th} biomass input installation produces 0.8 bcm of Bio-Methane. The Total Capital Investment for such a plant is estimated to be 500 million €.

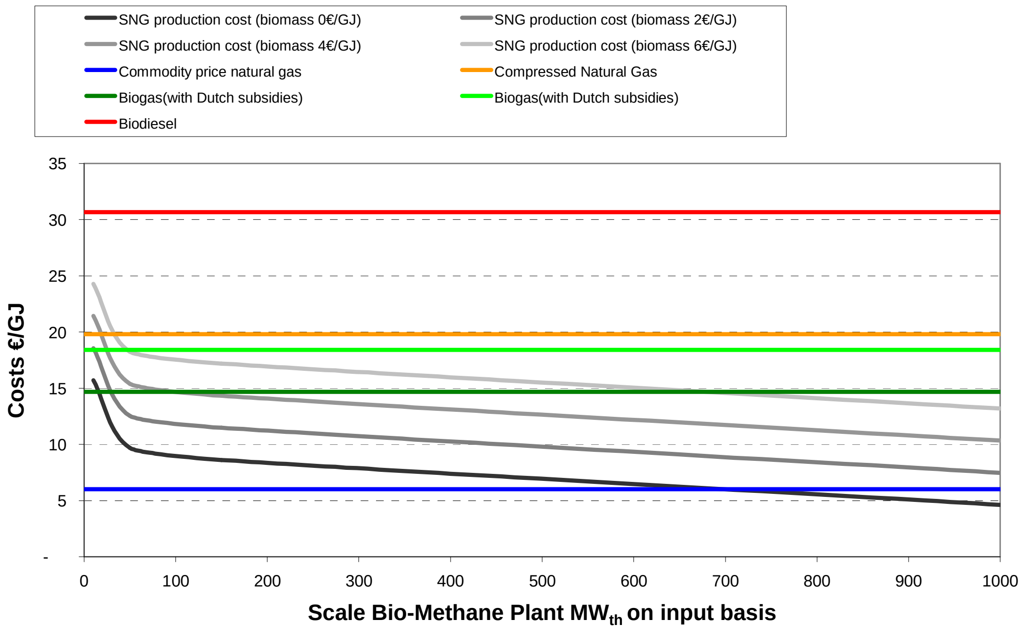

Figure 3.2: Production costs for Bio-Methane

As can be seen from the figure the production costs for Bio-Methane are higher than for fossil natural gas (assumed natural gas price of 6 €/GJ or ±6 €/MMBTU) when no subsidies or CO_2 credits are taken into account. The cost for Bio-Methane decreases at larger scale, because the investments costs for the Bio-Methane production plant are strongly reduced on MW_{th} basis when the technology is scaled up. The specified costs for CNG and Biodiesel were market prices (they vary strongly). Because of the urgent need of reducing CO_2 emissions and replacing declining fossil fuels reserves it is to be expected that local governments will continue the incentives that were introduced to promote sustainable energy. Bio-Methane can easily compete with other sustainable alternatives like Biodiesel.

4 Future Activities

The interest in Bio-Methane is growing; several initiatives to demonstrate the thermal conversion of wood into methane are under development. The GoBiGas project in Gothenburg (Sweden) plans a demonstration on a 20 MW_{th} scale. The produced gas will be used as a BioFuel in 15 000 passenger cars.

HVC Group and ECN plan to build a 10 MW_{th} MILENA gasifier in combination with OLGA gas cleaning and a gas engine in 2012 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 for the 10 MW_{th} Combined Heat and Power (CHP) demonstration. This plant is considered to be a crucial intermediate step towards commercial Bio-Methane plants. The 10 MW_{th} CHP demo however is also considered to be a demonstration of a commercial size CHP unit. The plant therefore serves two goals. After a successful CHP demonstration further scale-up to a 50 MW_{th} or 0.04 bcm/year Bio-Methane demonstration unit is foreseen. Figure 4.1 shows the planned development trajectory.

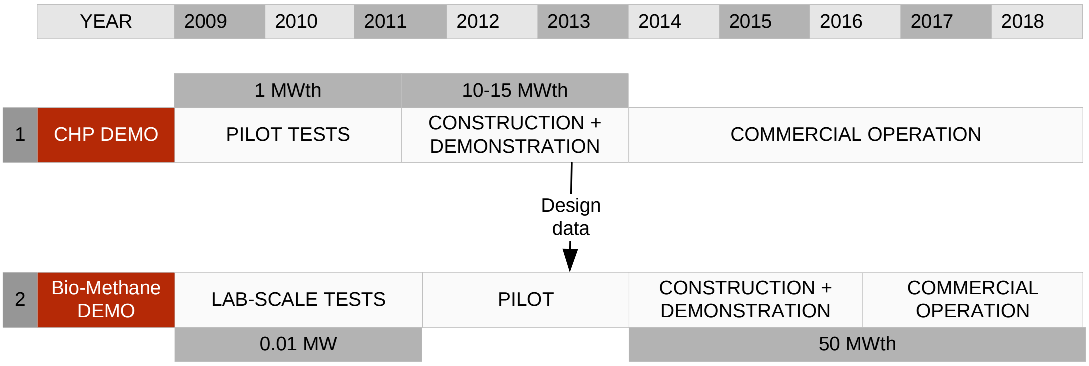

Figure 4.1: Planned development trajectory for MILENA Bio-Methane technology

5 Summary / Conclusions

Results from the lab-scale and pilot scale MILENA gasifiers are promising. The technology is tested extensively and results are up to expectations. The MILENA technology is ready for up-scaling. The 10MW_{th} MILENA CHP demonstration is scheduled for 2012. When results from this demonstration plant are according to expectations a 50 MW_{th} Bio-Methane (0.04 bcm/year) demonstration plant will follow.

Research on upgrading of the cleaned producer gas to Bio-Methane is still ongoing. Progress is made in increasing the lifespan of the catalyst. Additional long-duration tests are scheduled to verify if the improvements are sufficient to run a commercial process.

The upgraded gas produced by gasification of (waste) wood is in principle suitable for use as Bio-Methane to replace fossil natural gas. The most important deviations from conventional natural gas is the small amount of H_2 in the gas. The heating value of Bio-Methane is somewhat lower than the heating value of most natural gas standards, because the gas contains no hydrocarbons like ethane. The heating value is above the Dutch “Slochteren” standard.

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

Replacement of fossil Natural Gas by Bio-Methane is an attractive option to reduce CO_2 emissions and even to make them CO_2 negative if CO_2 sequestration is included.

The cost for Bio-Methane will be higher than the cost for fossil Natural Gas at this moment, but the difference is relatively small. Financial incentives are required (and available) to make the technology viable. Because of the urgent need of reducing CO_2 emissions and replacing declining fossil fuels reserves it is to be expected that governments will continue the incentives that were introduced to promote sustainable energy. Bio-Methane can easily compete with other sustainable alternatives like Bio-diesel or Bio-Ethanol.

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