Comparing the options to produce SNG from biomass

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COMPARING THE OPTIONS TO PRODUCE SNG FROM BIOMASS

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ABSTRACT: Natural gas is a popular fuel for obvious reasons. Substitute Natural Gas (SNG) resembles natural gas, but can be made from a renewable source: biomass. Both in Switzerland/Austria and in the Netherlands, technology is developed to produce BioSNG. Although similar on certain points such as using indirect gasification and tar scrubbing technology, both concepts are also essentially different. The differences have been quantified to be $6\%_{absolute}$ on energy efficiency from biomass to BioSNG: 64% for the Swiss/Austrian and 70% for the Dutch concept. The main reason for the difference originates from the necessity to produce only little tar during gasification in the Swiss/Austrian concept. The Dutch developments aim at large-scale plants of at least 100 MW for cost reasons, but also to enable the CO_2 co-product to be stored and produce power as a co-product. The Swiss/Austrian developments seem to aim at typically 50 MW plants for the supply of both SNG and heat at a high overall efficiency. Calculations however, indicate that the process leaves only little heat to export unless further decrease of the energy efficiency from biomass to BioSNG is accepted.
Keywords: gasification, gas cleaning, fluidized bed, efficiency, synthetic natural gas (SNG).

1 INTRODUCTION

Natural Gas is available from gas fields. The gas has been formed ages ago and mainly consists of methane (CH_4). Natural gas nowadays corresponds to roughly 25% of the world's primary energy consumption, and its share is still rising. The popularity can be attributed to its clean combustion, the high conversion efficiency, the option to store it, and the ease of distribution. Below, the historical and projected data on natural gas consumption are given for the EU25. The graph also shows the increasing gap between consumption and production in the EU, thus increasing the import dependency.

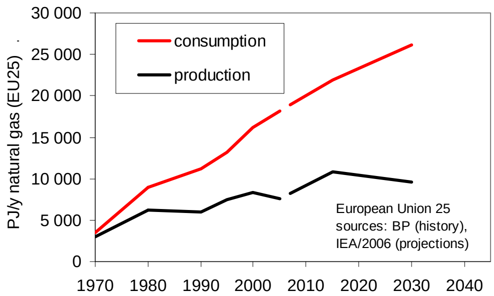

Figure 1: Natural gas consumption and production in the EU25

During the 70-ies, high natural gas prices and oil crises initiated the development of processes that could produce an "artificial" natural gas from coal. The gas was called Substitute Natural Gas (SNG), sometimes also called Synthetic Natural Gas. It has led to several plans to realize large-scale plants in the US, where coal is abundantly available. One plant actually has been constructed in North-Dakota and produces approx. 100 PJ of CoalSNG annually for almost 30 years now [1]. New developments concerning issues on security of supply and energy prices, re-initiated the interest in SNG from coal in the US.

SNG produced from biomass (BioSNG) has the additional feature that it is practically CO_2-neutral. Especially in Europe, this is the major driving force. Since the production process of BioSNG also offers the possibility to store CO_2 that is released as by-product, BioSNG not only avoids fossil emissions, but goes far beyond that. It actually takes two steps at once.

Initiatives to realise BioSNG plants based on gasification are developed in Austria, Switzerland, Germany, France, the Netherlands, and Sweden. Only few technological developments are ongoing. This paper deals with two distinct BioSNG developments in Austria/Switzerland and the Netherlands.

2 TWO DEVELOPMENTS

The two developments addressed in this paper find their origin in Austria/Switzerland and the Netherlands respectively. The Austrian/Swiss development is centered around the FICFB gasifier in Güssing in Austria, being the result of the research efforts of the University of Vienna. The Dutch development takes place around the MILENA gasifier and OLGA tar removal at the Energy research Centre of the Netherlands (ECN).

2.1 Austrian/Swiss BioSNG concept

The Austrian/Swiss developments are based on the success of the 2 MW_e CHP-plant in Güssing in Austria. This facility now reaches approximately 7,000 hours per year of operation and is one of the few biomass gasification plants worldwide that has this high availability, not considering the indirect co-firing plants.

The gasifier is sometimes referred to as FICFB (Fast Internally Circulating Fluidised Bed) and is based on the principle of indirect or allothermal gasification. This type of gasifier consists of two reactors: one where fuel is heated and a combustable gas is produced and another reactor where heat is generated for the first reactor [2]. The second reactor can be fueled with any fuel, at least being the solid char that remains from the first reactor. With this principle, two gases are produced: a combustable producer gas of approximately 15 MJ/m_n^3 and a flue gas.

The producer gas subsequently is cooled and filtered at 120-150°C. The gas then passes a scrubber to wash out the heavy tars and partially condens water. RME (Rape seed oil Methyl Esther), also called biodiesel, is used as washing liquid. The cleaned gas is directed to a gas engine.

In Güssing in Austria, a slip-stream plant has been added to demonstrate the process to Substitute Natural Gas (SNG). Gas is taken downstream the RME-scrubber and directed through additional cleaning steps to remove remaining sulphur and other contaminants that can not be tolerated by the nickel-based methanation catalyst. A fluidised bed methanation reactor has been developed by PSI in Switzerland for this application [3]. Finally, the gas is upgraded to meet the specifications of the application, which in Güssing is compressed gas for transport. This includes the separation of CO_2 and water. It also may comprise H_2 separation, which is recycled. The process is schematically shown below.

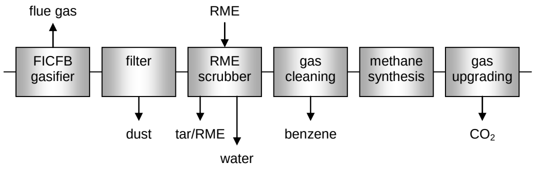

Figure 2: Swiss/Austrian BioSNG concept

2.2 Dutch BioSNG concept

The Dutch concept is based on the inventions of the Energy research Centre of the Netherlands (ECN), namely MILENA and OLGA. MILENA is the name for an indirect gasification technology, whereas OLGA is the acronym for an oil-based scrubber technology that removes tars.

ECN owns and operates the MILENA- and OLGA-technology on lab-scale (~5 kg/h) and pilot-scale (~160 kg/h). The MILENA has been tested extensively on different fuels by ECN and proved to be a highly efficient indirect gasifier. The concept has attracted the attention of the HVC-company, which started the work to realize a 10 MW (demolition wood input) CHP plant based on the MILENA gasification technology and OLGA tar removal technology.

The patented OLGA-technology has been licensed to Dahlman. Dahlman has now supplied the technology for two clients in France and Portugal and is preparing the supply of systems up to 150 MW. OLGA is characterized by its versatility. It can be coupled to all kind of gasifiers, it can reduce tars to very low level, it can handle gases with tar concentrations as high as 40 g/m_n^3 or even more, it can treat gases produced from clean biomass as well as waste like RDF, etc. [4].

The 10 MW CHP-plant as planned by HVC will demonstrate the CHP-technology based on MILENA and OLGA, but will also be the step towards large-scale SNG-plants. For this, additional gas conditioning will be added as well as methanation and gas upgrading units. The strategy of ECN for components downstream OLGA is to maximize the use of existing technologies and materials/catalysts, currently available for mainly (petro)chemical industry. The methanation will be done using e.g. the commercially available TREMP technology by Haldor Topsøe. ECN is in the process of assessing gas conditioning options. For this, ECN has a complete lab-scale system available to test the options. The following figure schematically shows the Dutch concept, which is based on MILENA gasification and OLGA tar removal. In the Dutch concept, gas conditioning steps downstream OLGA have not yet been fixed, but should preferably be based on existing commercially available technologies.

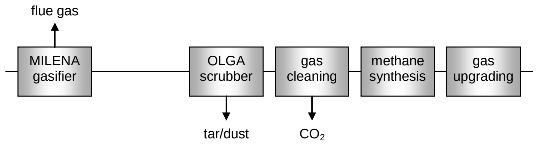

Figure 3: Dutch BioSNG concept

3 THE SIMILARITIES

The Swiss/Austrian and the Dutch concept to produce Substitute Natural Gas (SNG) from biomass generally are similar. Both rely on indirect gasification as the key process. Indirect gasification has been recognized as the most suitable method because it produces an essentially N_2-free gas without the need to have an expensive and energy-intensive air separation unit for oxygen production. Furthermore, fuels are converted completely because indirect gasification includes combustion of any unconverted fuel that may be left upon pyrolysis/gasification. In [5] it has been calculated that indirect gasification can produce SNG with $7\%_{abs}$ higher efficiency as the second best, being oxygen-blown circulating fluidized bed gasification. This even becomes almost $9\%_{abs}$ if power production and consumption are included in the calculation.

Both indirect gasification concepts FICFB and MILENA operate at approximately 850°C gasification temperature in a fluidized bed reactor. The gasification zone is coupled to a combustion reactor at approximately 930°C, where the heat is produced and transported to the gasification zone by circulating bed material. Both gasifiers circulate ~40 kg bed material per kg biomass input.

The Swiss/Austrian and Dutch concept both rely on tar removal by scrubbing. By this method, tar is removed without removing methane that has been produced in the indirect gasifier. The methane production in the indirect gasifier is relatively high and is important for the overall efficiency from biomass to SNG. The tars that are collected by the scrubbers, are recycled to produce (part of) the energy needed for the gasification plant.

Further gas cleaning and conditioning in the Swiss/Austrian and Dutch concept comprise all kind of units, but both at least include sulfur removal, catalytic methanation, CO_2-removal, and drying.

4 THE DIFFERENCES

4.1 Gasification and tar removal

Although both concepts rely on indirect gasification as the principle process to convert solid biomass into a gaseous fuel, there are some important differences. The technologies are shown in the figure below.

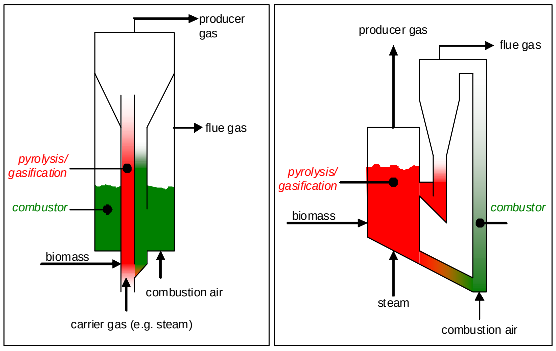

Figure 4: Indirect gasification technology MILENA (left) and FICFB (right)

The FICFB-based concept is based on a smart integration of gasification, gas filtering, and gas scrubbing in which tar plays a crucial role, because the gas cleaning devices limit the tar content that can be tolerated in the gas. Since the filter operates below 150°C, the tar dew point should be less than 150°C. Furthermore, the scrubber consumes RME to remove tars. The consumption of relatively expensive RME (5-10 times the price of wood in €/GJ) will become unacceptable at high tar loads. In the present situation, the consumption of RME is ~2% on energy basis [6]. For all the reasons as mentioned above, the Austrian FICFB aims at relatively low tar production, contrary to the Dutch MILENA.

The low tar yield in the FICFB concept has been realized by promoting tar reforming in the gasification reactor. This is achieved by using carefully selected olivine as bed material. Also steam is required to promote the steam reforming and steam gasification reactions. Typically, this amounts to 25% steam related to the mass flow of wood on top of the steam already available from the moisture content of the wood (also typically 25%) [7]. The MILENA gasifier only needs about 5% of steam in the gasifier, in order to create fluidization at the bottom of the gasification zone and to keep the bed material circulation going. Tar content in gas from MILENA is not considered to be of relevance, since OLGA has proven to remove tars from high concentrations to very low concentrations.

The FICFB concept enables reforming of tars, but also creates good conditions for biomass steam gasification (steam, good contact, high particle residence times). Therefore, the conversion of solid biomass in the gasification zone is relatively high. The carbon conversion in the gasification zone is estimated to be around 90%, leaving 10% of carbon as solid char, which is transported to the combustion zone. The MILENA gasifier operates at 80-85% carbon conversion, leaving 15-20% char for the combustion zone.

Because of the differences in conversion and steam consumption, the energy balances of FICFB and MILENA are different. The FICFB gasification zone requires relatively high amounts of heat to supply the energy for the endothermal reforming reactions as well as the heating of the relatively large amount of (pre-heated) steam. At the same time, the FICFB gasifier produces only limited amount of char, which is used to supply the heat by combustion in the combustion zone. The result is that the combustion zone needs additional fuel. This is supplied by circulating producer gas from a position downstream the RME-scrubber to the combustion zone of the FICFB-concept. This amounts to 20-25% of the gas volume produced in the gasifier [8,9]. This is a flexible way of controlling the energy balance and temperatures, but involves an energy loss, since the recycled gas is cold and requires energy to be heated to combustion temperature. This also increases the amount of air needed in the combustion zone, which also needs to be heated.

The MILENA gasifier needs less energy in the gasification zone, because conversion within the gasification zone is lower and conditions are such that steam reforming hardly takes place. At the same time, more char is left to supply the heat for the gasification zone from the combustion zone. But also the MILENA concept generally will have to deal with an energy demand in the gasification zone that cannot be supplied by char combustion alone. MILENA therefore mostly also needs an additional gas recycle to cover the energy demand. This however, can be supplied internally. The MILENA concept offers the option to intentionally leak producer gas from the top of the gasification zone to the combustion zone. This can be done by controlling the pressure difference between the two zones. This turns out to be an excellent way of controlling the energy balance. Moreover, it is very efficient, since the gas is already at high temperature. The present FICFB design does not seem to have this option, since the gas "leakage" would have to follow the bed material circulation at the bottom of the gasifier, where steam is added, see Figure 4. The result would be that steam is flowing to the combustion zone, rather than the hot producer gas.

The above-mentioned differences between FICFB/RME and MILENA/OLGA have been quantified using in-house models at ECN. The main general assumptions are given in the table below.

Table I: Overview of general assumptions for the calculation of the efficiency

Biomass	Wood
Biomass moisture content (wet basis)	25%
Gasifier temperature	885°C
Combustion temperature	930°C
Air pre-heat for combustion	400°C
Steam pre-heat	150°C
Reactor heat loss total (of biomass LHV)	1%
Tar recycle from scrubber to combustion zone	100%

The result is that the energy of the tar-free producer gas (downstream scrubber), that is available for further treatment, is 78% for the MILENA-OLGA concept and 72.5% for the FICFB with RME-scrubber.

4.2 Gas cleaning and SNG production

In order to use the gas leaving the tar removal unit (RME-scrubber or OLGA-scrubber), it needs additional cleaning depending on the application. For a gas engine, this may only be a minor issue, but for catalytic upgrading to SNG, this is not trivial.

The RME-scrubber has been developed for the use of a gas engine and leaves typically 1-2 g/m_n^3 naphthalene in the gas [8]. Further removal of naphthalene would require both lower temperature of the scrubber and more RME as the oil will get saturated. The OLGA-scrubber has also been developed initially for the use of a gas engine, but leaves typically less than 40 mg/m_n^3 naphthalene in the gas, corresponding to the general standards for gas engines. Oil consumption due to saturation is avoided, as the tars are stripped out of the oil in a separate step. Both the RME-scrubber and the OLGA-scrubber hardly remove benzene. Both the Dutch and the Austrian/Swiss developments aim at removing these aromatic molecules. This results in limited mass flow, but may contain typically 5-10% of the energy of the producer gas. In the Austrian/Swiss concept, aromatics could simply replace part of the recycled producer gas and therefore have hardly any effect on the overall efficiency. The Dutch concept however, does not need this additional energy in the gasifier. So, for this reason, the Dutch concept includes ways to convert the aromatics (mainly benzene) into H_2, CO and CH_4 in order to keep the energy content in the gas. A pre-reformer unit is envisaged in the Dutch concept.

Another difference between the Austrian/Swiss and Dutch concept seems to be the location of the CO_2 removal. The Austrian/Swiss concept does foresee an amine washer downstream the methanation catalyst, whereas the Dutch concept reckons that CO_2-removal upstream the methanation is more efficient. This is possible in the Dutch concept, because the gas conditioning includes reactors that have catalytic activity towards the water gas shift reaction, thus producing CO_2. This also means that steam is needed more upstream in the system than in the Swiss/Austrian concept where the methanation is the first reactor that takes care of the water gas shift reaction. This creates the option to use the steam, which is already available in the gas from the gasification (typically more than 30 vol%) before the water in the gas is removed through washing and/or compression of the gas.

The Austrian/Swiss concept includes a fluidized bed methanation reactor that has been developed specifically for the biomass-to-SNG process by PSI and CTU from Switzerland [3]. One of the unique features of this methanation reactor is that it is able to cope with ethylene as one of the challenging components for more conventional methanation reactors [10]. The Dutch concept relies on existing fixed bed methanation technology that will require upstream ethylene hydrogenation.

The picture below summarizes the two systems from biomass to SNG in a simple scheme.

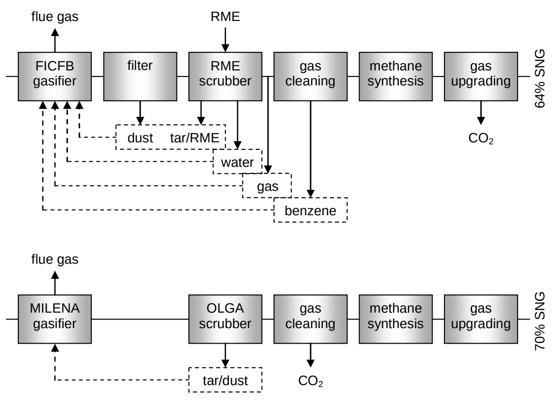

Figure 5: The Austrian/Swiss (top) and Dutch (bottom) concepts for the production of SNG from biomass

4.3 SNG efficiency

As shown above, the gasification and tar removal technology have an energy efficiency of 72.5% for the Swiss/Austrian and 78% for the Dutch concept. The efficiency to methane depends on the composition of the gas and is close to 90%. A small difference is caused by the fact that the H_2 and CO concentration in the Swiss/Austrian concept is higher and the CH_4-content is lower than the gas produced in the Dutch case. The overall energy efficiency from biomass to SNG is calculated to be 64% for the Swiss/Austrian concept and 70% for the Dutch concept.

4.4 Heat production

All the energy that has not been converted into SNG or has been lost by radiation, theoretically is useful heat. Using the calculated values and assumptions as presented above, the efficiency to useful heat equals 34% for the Swiss/Austrian concept and 29% for the Dutch concept. The process itself however, consumes a considerable part of this heat for steam production. Furthermore, the regeneration of amine liquids that may be used to remove CO_2, requires a considerable amount of heat.

For the FICFB concept, the steam production for the gasifier requires approximately 4% of the biomass energy input capacity. Another 14% is needed to regenerate the amine liquid for CO_2 separation and 6% is needed to generate steam that is needed for the methanation to have sufficient H-atoms for complete CO conversion. This leaves only 10% of heat that may be exported. This roughly is the amount of heat required to dry biomass from 40% to 25% moisture.

In the Dutch concept, the heat surplus may be more, despite the higher efficiency to SNG. This is because of (1) the relatively low steam demand of the gasifier and (2) the water gas shift reaction taking place within the gas cleaning section, where water condensation has not yet taken place.

Apart from the heat demand of processes within the SNG-plant, heat may also be used to generate power. This is only worth the investment if the biomass capacity is at least several-hundreds of MW_{th}.

4.5 CO_2 co-product

An important co-product of any process from biomass to SNG is CO_2. This is relatively clean CO_2 that can be stored for additional CO_2-reduction. Roughly, approximately 40% of the C from the biomass ends up as CO_2 that can be stored. Another 20% ends up as CO_2 in the flue gas, and the remaining 40% becomes CH_4.

CO_2 co-production for e.g. underground storage however, needs large scale to be economically feasible. For small scale applications, CO_2 export to e.g. greenhouses might be considered, although this involves extensive quality control.

5 CONCLUSIONS

Natural gas is a popular fuel for obvious reasons. It is simple, clean, easy to distribute, storable, and available. But in certain regions such as Europe, the consumption exceeds the production and the shortage is expected to further increase in time. Furthermore, natural gas is a fossil fuel and thus contributes to the climate change.

BioSNG is a gas that resembles natural gas, but is produced from biomass and does not have these disadvantages.

Both in Switzerland/Austria and in the Netherlands, technology is developed to produce SNG from biomass. Both concepts have selected indirect gasification technology because of efficiency reasons. Furthermore, both concepts use scrubber technology to remove tars and keep the methane in the gas.

The Swiss/Austrian concept is based on the successful CHP-plant in Güssing. The concept is characterized by a smart integration of units, where a low tar production is a prerequisite. The Dutch concept is based on the successful OLGA tar removal technology that creates an extra degree of freedom: the optimization of the efficiency. The differences between the two concepts have been quantified and estimated to be $6\%_{abs}$ on the energy efficiency from biomass to BioSNG: 64% for the Swiss/Austrian concept and 70% for the Dutch concept.

Furthermore, it has been shown that the remaining energy largely is needed for heat demand within the plant. Especially, the Swiss/Austrian concept needs considerable heat for the production of steam to be used within the process. The Dutch concept might consider co-production of power, since it aims at large scale application. This will also allow the co-product CO_2 to be stored for additional CO_2 credits.

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