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Production of biomass based methane in Styria - perspective for short term applications

A Master Thesis submitted for the degree of

“Master of Science”

supervised by

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Graz Feb. 2008

Affidavit

I, Dipl.-Ing. Norbert Machan hereby declare

1. that I am the sole author of the present Master Thesis, “Production of biomass based methane in Styria - perspective for short term applications” 53 pages, bound and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

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Abstract

This work discusses two principal ways to produce biomass based methane for natural gas grid applications based on the available biomass feedstock and local conditions in Styria. The result of this work provides the basis for the pre-selection of the most promising biomass conversion concept and a mid term scheduled project with the aim to develop a detailed technical realization concept for biomass based methane production in Styria.

The two conversion paths investigated were the biological conversion of organic feedstock like agricultural residues, energy crops and residues from communities and agro industries and the thermochemical conversion of woody biomass. Therefore feedstock availability, state of technical development and cost affects were investigated.

Based on the available potential of feedstock used within the biological conversion path a total energy equivalent for biomass based methane in Styria of nearly 2,800,000 MWh was calculated. The production of thermochemically produced biomass based methane seems to be more difficult concerning a secured and adequate supply of woody biomass. Assuming that 100,000 solid cubic metres energy wood can be mobilised in Styria, a theoretical biomass based methane potential of approximately 245,000 MWh/a could be achieved.

From the technical point of view the production of biomass based methane along the biological chain is quite well developed, while methane along the thermochemical conversion path respectively SNG (Synthetic Natural Gas) production seems to be in an early stage of development.

The most effecting parameter for production costs of biomass based methane along the biological conversion path are feedstock costs and costs for feedstock upgrading demands. Therefore the utilization of liquid manure and bio waste seems to be auspicious. Production costs of < 5 €-Cent/kWh can be achieved at biogas production capacities of 500 m^3/h.

The most cost affecting parameters within the thermochemical path are investment and operating costs for gas upgrading devices. Production costs in the range of 6 €-Cent/kWh can be achieved at production capacities of >6,250 m^3/h. Compared to an average energy price for natural gas of 2.1 – 2.6 €-Cent/kWh it can be pointed out, that in the case of feeding the biomass based methane into the natural gas grid both conversion paths need different amounts of subsidies to be competitive to the current energy market at the moment in Austria.

Summing up the process based on the biological conversion was selected to be investigated more detailed to be able to develop a concept for realisation.

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1. Introduction

The whole area of Styria amounts 16,392 km², which corresponds 19.5 % of the Austrian area. 54 % of Styria is covered with forest; more than 25% of the country's territory is agriculturally used. In this area especially biogas and bio fuel production are possible.

The whole gross energy consumption of Styria amounts 52,713 GWh//a (Amt d. StL, 2005).

The quantity of imported energy is 67 % of gross energy quantity and the quantity of renewable energy is nearly 26% of end energy use. One way to increase the amount of renewable energy quantity is to produce gas from biomass for natural gas grid applications. In Styria approximately 1.4 Mrd. m³ of natural gas are used per year. This corresponds to an energy amount of nearly 14,000 GWh per year.

1.1 Motivation

Steirische Gas-Wärme GmbH intends to develop a comprehensive technical and economical concept to produce methane from biomass in Styria within the next two years.

Methane from biomass can be produced along different conversion paths, which require different kinds of feedstock and technologies for the conversion process. Based on this concept an efficient and short term realisation of projects should be possible, with the aim to provide 5 – 10% of the total natural gas consumption in Styria with biomass based methane within the next 10 to 15 years. The choice of the most promising technology based on the local conditions in a selected area, is one of the most critical decisions investors have to make in a first step to realize successful and sustainable projects. This important investigation and pre-selection is the topic of the presented master thesis.

1.2 Purpose of the study – initial situation

Basically there are several ways to make use of organic feedstock for different kinds of energy production purposes. The conversion paths pictured in Figure 1 represent an overview of the production of different secondary energy recourses in particular for liquid and gaseous fuels.

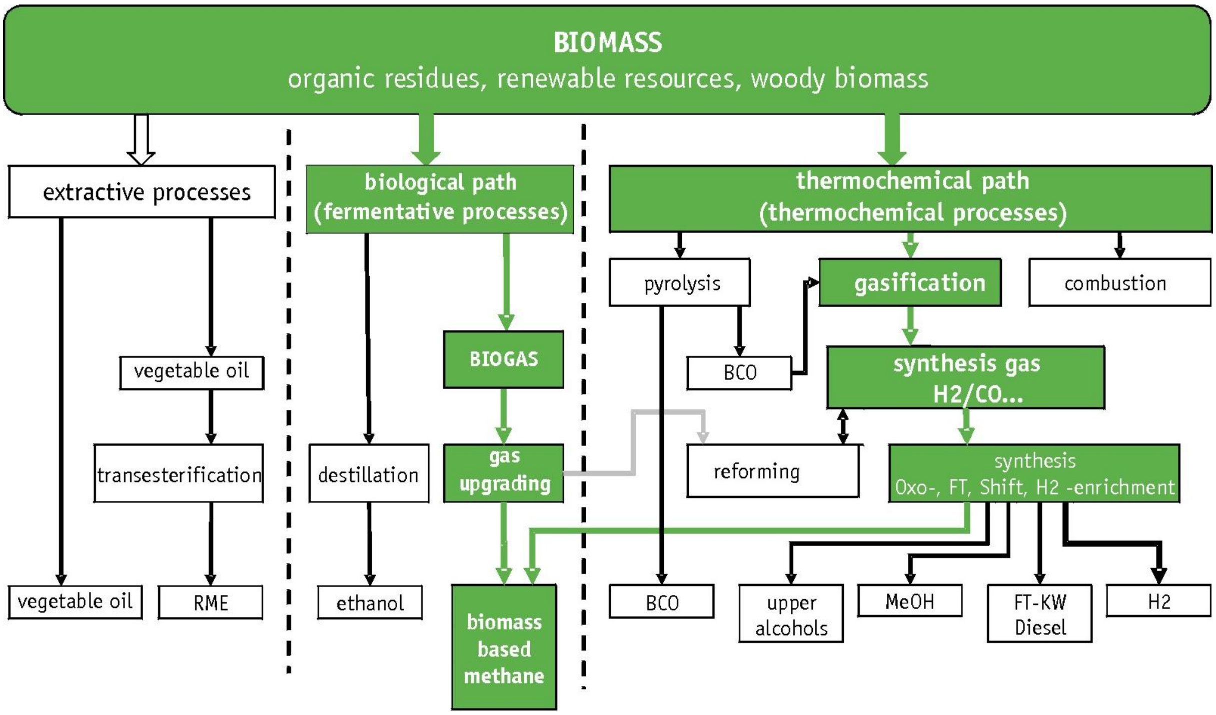


Figure 1: *Overview of different conversion processes from biomass to energy products*

The green paths in Figure 1 show the two investigated paths of biomass based methane production that are discussed in this study. Based on the available organic feedstock in Styria, different conversion technologies can be used to produce biomass based methane for natural gas grid application. The most common conversion path in this matter is the biological conversion path where organic biomass is degraded by anaerobic digestion (fermentative process). Biogas, which basically contains methane (50 – 70%) and carbon dioxide (30 – 50%) is cleaned using a upgrading device to methane contents of >97%.

A new and very interesting conversion path is the thermochemical conversion path. This path is mainly driven by the gasification process, where a so called synthetic gas is produced in a first step. The main components of this gas are hydrogen, carbon oxide, carbon dioxide and a small amount of methane (7 - 10%). To increase the amount of methane another process step has to be performed where the components H_2 and CO are converted into CH_4 and CO_2 via catalytic methanation. Finally gas cleaning and gas upgrading devices are required to get an appropriate gas quality for natural gas grid injection. These upgrading and cleaning steps are not pictured in Figure 1 separately.

Additional other conversion processes are also pictured in Figure 1. These can be considered in competition to the biomass based methane conversion process in matters of feedstock availability and are not discussed in the study in detail. Based on the available feedstock and the opportunities of production technologies the study should give a recommendation concerning the most promising way to produce biomass based methane for grid application in Styria for a short and midterm realization concept.

1.3 Main objectives

In this chapter the main objectives of the presented work are point out.

Which are the basic input materials for each conversion path?

To answer this question general information about the characteristics of the feedstock used at the thermochemical conversion path and the biological conversion path will be discussed.

How large is the biomass based methane potential based on the feedstock available in Styria?

Based on the suitable categories of feedstock for each conversion process, the amount and availability of these substrates in Styria will be investigated.

Further questions in this context were local conditions (concentration, natural gas grid), current applications, stakeholder and ownership as well as future perspectives.

What are the common technologies along the different conversion paths?

Based on the selected feedstock, the different technologies along the conversion path from the raw material to the end use as substitute for natural gas (biomass based methane) will be discussed.

Additional questions to be answered are:

- available technologies
- status of development of these technologies
- expected schedule for market penetration - research and development and examples

What are the production costs?

Production costs for biomass based methane are discussed based on different kinds of feedstock and conversion models.

What is the most promising conversion path to produce biomass based methane in Styria?

Finally the most promising conversion path should be recommended based on the results of the different technical, economical aspects and local conditions.

1.4 Structure and methodology of the work

To get basic information on the different topics, the work includes a study of available literature (studies, expertises….) supplemented with interviews e.g. with plant operators, raw material deliverers and scientists in the different areas of interest.

The work included the following main work packages:

1. Survey of available feedstock in Styria.

In this work package the question of the amount, availability and applicability of materials will be discussed in relation to the principle two processes (thermochemical and biological conversion process), which are used to produce bio-methane.

2. Description of the natural gas grid in Styria

This work package includes the description of the natural gas grid in Styria related to the local conditions for reasonable injection opportunities.

3. Investigation of conversion processes.

Based on the individual feedstock conventional conversion processes will be discussed for the two principle trails of thermochemical conversion and biological conversion. Therefore technical developments will be also represented as well as required plant capacities and material mass flows of the process.

4. Production costs

Within this work package cost effective parameter are discussed for different production models. These are e.g. feedstock costs, production capacities, costs for biomass upgrading demand and costs for biogas upgrading demand.

5. Evaluation and selection of the most promising process for subsequently detailed development of technical concepts.

This work package will compare the different kinds of processes based on economical values for a proposed project realization within the next 2 - 4 years.

Further it should give an outlook for technologies which will be available on the market in future.

2. Local conditions for biomass based methane production

2.1 Feedstock based on biomass- general conditions

Biogas plants usually use substrates with high water content for the production of biogas. Due to changes of legal and economic framework in the past, a diversity of technologies were developed, which use different kinds of appropriate organic substrates to produce biogas by anaerobic digestion. The substrates discussed regarding the organic conversion path are based on those materials, that have the largest share in biogas production and can be separated into agricultural substrates like organic fertilizer (manure), residues from agricultural cultivation, renewable recourses (energy crops) e.g. maize silage and grass silage, substrates from processing agro industries like beer brewing, alcohol production, potato processing, sugar processing and fruit processing, organic residues from households and communes e.g. bio waste, leftovers and expired food, grease separator, market waste and finally sewage sludge (Inst. für Energetik und Umwelttechnik et. al 2004).

In Austria a couple of studies were performed to appreciate the biogas potential based on different assumptions concerning the range of feedstock and their availability. A comparison of some selected studies state a potential between 250 Mio. m³ and 1,3 Mrd. m³ biogas, depending on the assumptions the study is based on (see Figure 2).

Figure 2 shows the range of the published biogas potentials based on a selected number of authors. The wide range of the predicted biogas potentials based on the individual feedstock and the according assumptions represents the difficulty to get serious and reliable information about this important issue. Therefore the need of detailed potential inquiries at the plant location of energy production becomes an important significance.

In Styria the Landesenergieverein published a potential study in 2005 (Puchas et. al, 2005). This study is the only published study dealing with the conditions exclusively in Styria.

Many discussions in this work are based on this study and consider the available so called short term potentials that can be used within the next few years without essential changes in current operating structures. Moreover new findings are supplemented based on interviews and own inquiries.

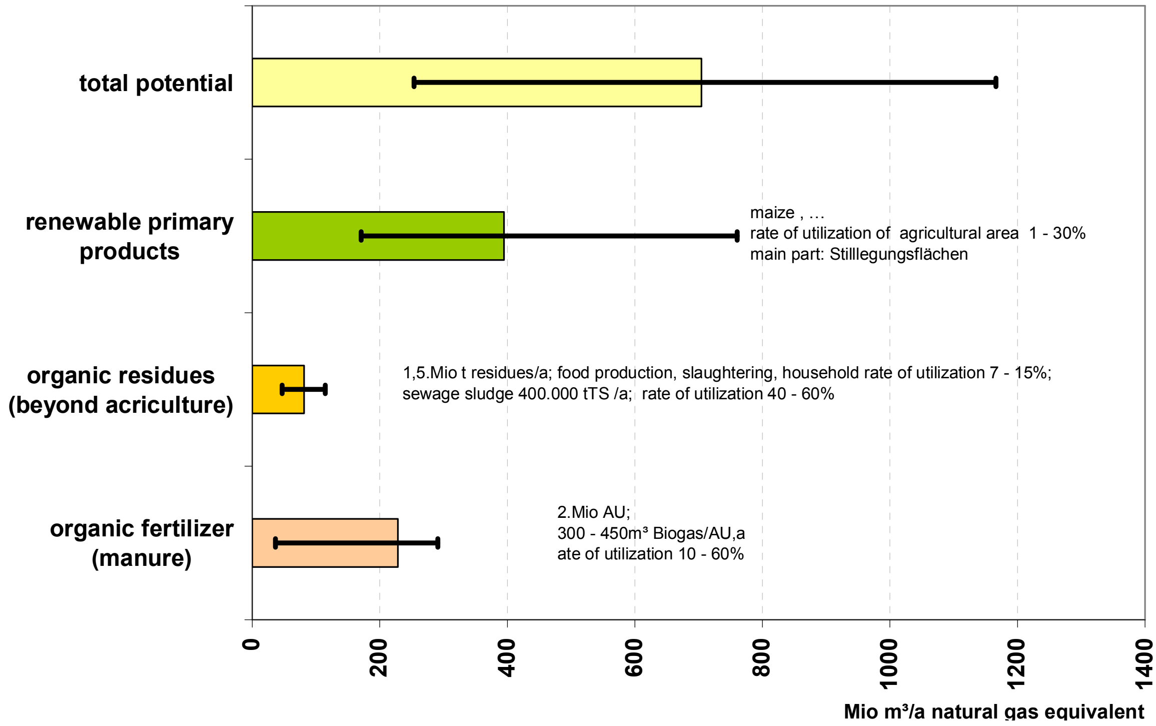


Figure 2: *Range of biogas potential for different substrates in Austria. Source: Dissemond et al 1993; Hornbach 2005; Jungmeier et al. 1996; Amon 2001a; ECG 2003; AU…Animal Unit; TS…dry substance*

A new option to produce methane from biomass is the gasification of solid biomass to a syntheses gas followed by the conversion to methane by an additional methanation unit (see also chapter 3.2). This process can be integrated in the path of thermochemical conversion (see Figure 1). The feedstock used is solid biomass, which usually contains woody biomass fractions from different sources and with different characteristics (especially regarding the water content, particle size and their composition).

Typical materials are wood chips, bark and saw dust from wood industry and residues from thinning, fellings and landscape conservation. Due to the Austrian green electricity act 2002 (lucrative feed-in tariffs for biomass based electricity production) the demand of wood for energy application increased dramatically and the supply of bigger power stations seems to become endangered. In the year 2007 nearly 14.9 million solid cubic meter wood were used for energy applications in Austria (figure 3). This amount corresponds to an energy quantity of approximately 140 PJ (39 TWh). To compensate this additional demand, new wood production technologies were investigated in the last few years. Other projects focus on the production of energy crops where e.g.: poplar is cultivated at so called short rotation areas.

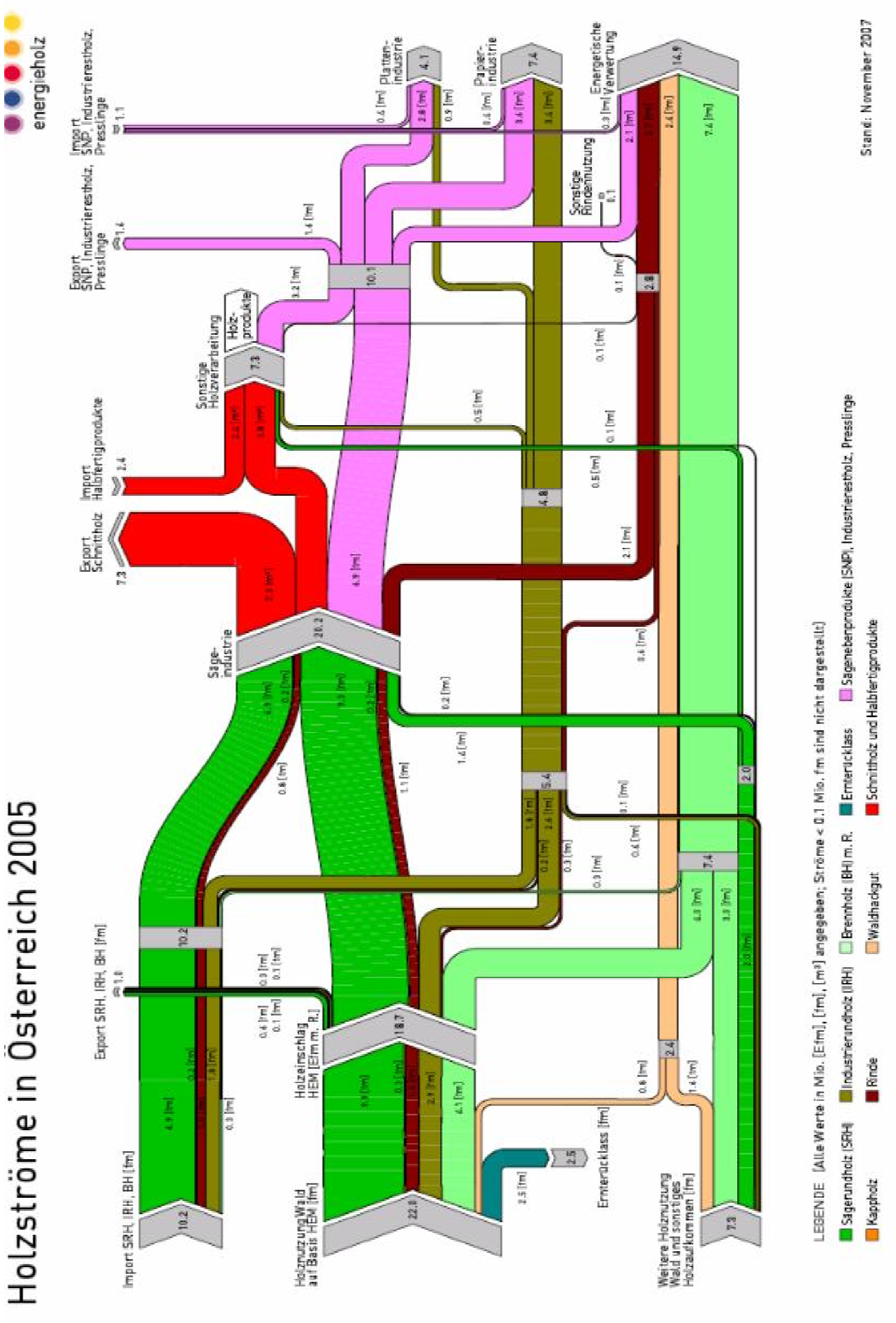


Figure 3: *Wood balance sheet for Austria (Hagauer et al, 2007)*

Figure 3 shows the balance sheet of the wood streams in Austria based on a consolidation of different sources in 2005. Wood fractions are stated from the quantity over different processing paths to a wide variety of products.

Regarding the energy application path it can be found that nearly 15 Mio solid cubic metres are used for energy applications (CHP plants, wood chip, pellet, briquette and split log boiler). Nearly 11.5 Mio solid cubic metres are used in the paper and slap industry. The different use and application of wood based biomass leads to a competition within the different markets, why increasing wood demand for energy applications becomes more dependent on different market mechanisms. Especially the fractions of waste wood are no longer available for additional energy projects presently.

In the following chapter the availability of different kinds of feedstock is discussed, based on the local conditions in Styria.

2.2 Potential of feedstock in Styria

2.2.1 Characterisation of discussed feedstock and observed regions

Category of feedstock	**Substrate**	**Methane yield (m³/t w.b.)**
	biological conversion	
Agricultural substrates	organic fertilizer (manure)	
	liquid manure from animal husbandry swine (1 AU = 6#), cattle (1 AU = 1#)	15 – 25
	chicken (1 AU = 60#)	25 – 55
	renewable resources	
	maize silage (based on set-aside land)	80 – 120
	grass silage	85 – 120
Substrates from processing agro industries	brewery residues	100 – 130
	whey	15 – 25
	mash	18 – 30
	fruit marc	160 – 200
	marc	15 - 30
Organic residues from households and communes	organic waste	40 – 70
	leftovers	25 – 160
	grass from military facilities and landscape conservation	80 - 120
Sewage sludge	sewage sludge	5 – 10
	thermochemical conversion	
Woody biomass	wood from forest	375

***Table 1**: Characterisation of investigated feedstock in Styria for biological and thermochemical conversion path, AU…animal unit, w.b…..wet base; #....number*

Table 1 shows the different kind of feedstock discussed within this study at the districts of Styria see Figure 4.

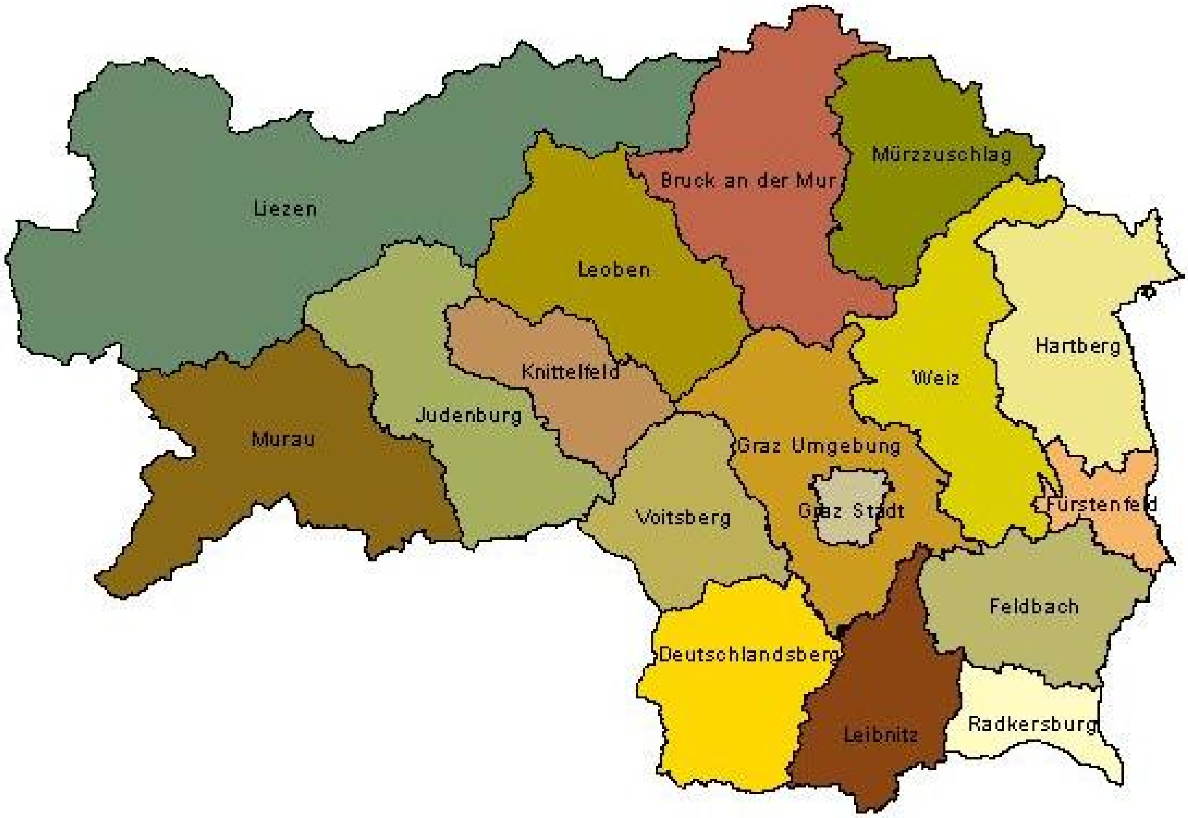


Figure 4: *Map of the districts of Styria*

2.2.2 Agricultural substrates

Agricultural substrates can be divided into organic fertilizers on the one hand and renewable resources (energy crops) on the other hand. The term “organic fertilizer” describes organic substrates from agriculture, which are used for fertilizing purposes. In case of biogas production this mainly means the liquid manure from animal husbandry (swine, cow, chicken). Many agricultural biogas plants use this kind of substrate for energy production. Other plants use energy crops, which are cultivated for energy production beyond the food and animal feed production. They become important with the discussion of the lack of fossil resources for energy production and their environmental impact and consequently with the implementation of feed-in tariffs for the electricity production based on renewable resources. Under consideration of legal guidelines, which are specified e.g. in the EU decree Nr. 1251 Verordnung (EG) Nr. 1782/2003, set-aside land can be used for cultivation of energy crops.

The most common crop used for biogas production is maize and maize silage, but there are still a lot of additional crops under investigation.

2.2.2.1 Organic fertilizer

The potential for organic fertilizer was calculated based on of the current livestock in Styria (Puchas et al, 2005). The most important animals taken into account were swine, cattle and chicken. Styria has an animal livestock of 362,066 cattles, 920,849 swine and 4,366,019 chickens, based on the data from 2003 (Puchas et al 2005, pp 2-23). This corresponds to approximately 560.000 AU (see also Table 1). Under consideration of an assumption of a 50% reduction Puchas published a total energy potential of 890,693 MWh/a on base of methane production. Therefore the main contribution comes from cattle with more than 600.000 MWh/a. Nearly 50% of the potential is located in the south east of Styria in the districts Hartberg, Weiz, Feldbach and Leibnitz which are 4 of 17 districts in Styria that have intensive animal husbandry.

Based on inquiries from 2004/2005 Styria has an animal livestock of 330,156 Cattles, 863,166 swine and 4,366,019 chicken (FA 10A, 2007 pp 63, 72) which corresponds to an energy potential of nearly 830,364 MWh/a → - 7% (based on similar calculation assumptions like Puchas). Therefore the potential corresponds to the animal livestock which has to be taken into account for long term considerations.

Figure 5 shows the distribution of liquid manure of different kinds of animals in Styria.

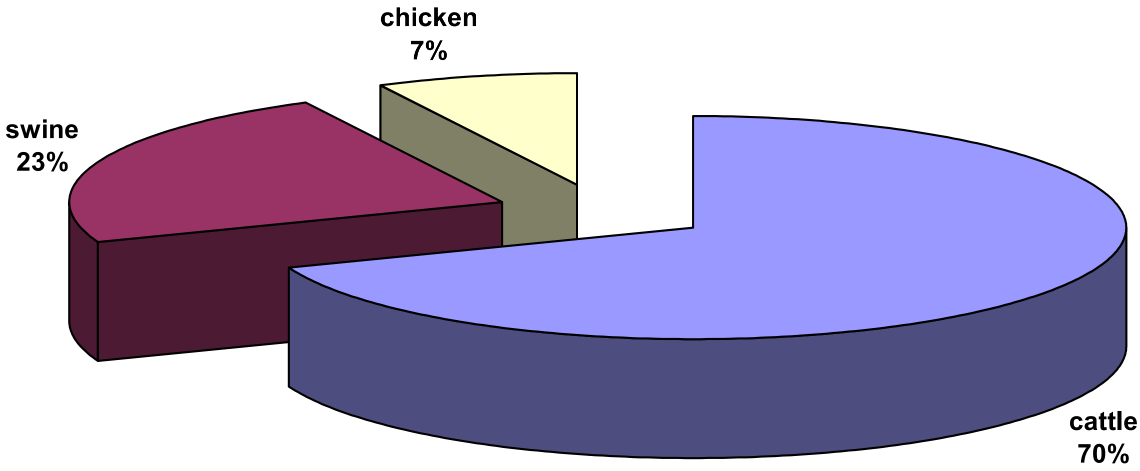


Figure 5: *Fraction of biogas energy production contributed by organic fertilizer of cattle, swine and chicken in percentage of the total energy production of 890.693 MWh/a in Styria (Puchas et al., 2005);*

The concentration of the animal husbandry in the south and east of Styria and the utilization of the animal manure as fertilizer leads to some problems concerning the nitrate loading of the ground water in this area. This problem was mainly caused by the application of the liquid manure as fertilizer to the agricultural areas by farmers (Frank, 2007). Another bad influence is the smell, which leads to a negative affect to the neighbourhood. One solution could be the degradation of the animal manure within the biogas process and the utilization of the digested substrate in kind of a central digestate utilization plant to produce nitrate fertilizer. The high concentration of the raw material favoured the construction of bigger plants and therefore leads to a better economy for this kind of plants.

2.2.2.2 Renewable resources

In the case of renewable resources the potential is calculated based on the available agricultural areas. Therefore a big potential is expected in the cultivation of the set-aside land in Styria (Puchas et al., 2005 pp 2-19ff). In these areas only energy crops are allowed to be cultivated. Bases on Puchas study, an area of 12,681 ha from the total agricultural area of 228.840 ha in Styria was declared as set-aside land in 2003 (AMA, 2003). The largest areas are located in Feldbach, Hartberg and Leibnitz (south east of Styria). The energy equivalent was calculated on the base of maize silage and only for cultivating the set-aside land. Therefore 40 – 50 t w.b./ha·a biomass yield and a methane yield of 100 m^3/t w.b. was assumed. The energy equivalent for biomass based methane was calculated with 573,562 MWh/a (10 kWh/m^3 methane). This also corresponds to the potential of the substrates based on animal husbandry (organic fertilizer).

This amount has to be considered critically because the same area could also be used to grow plants for other energy conversion paths like heat and power production (elephant grass, poplar.) or fuel production.

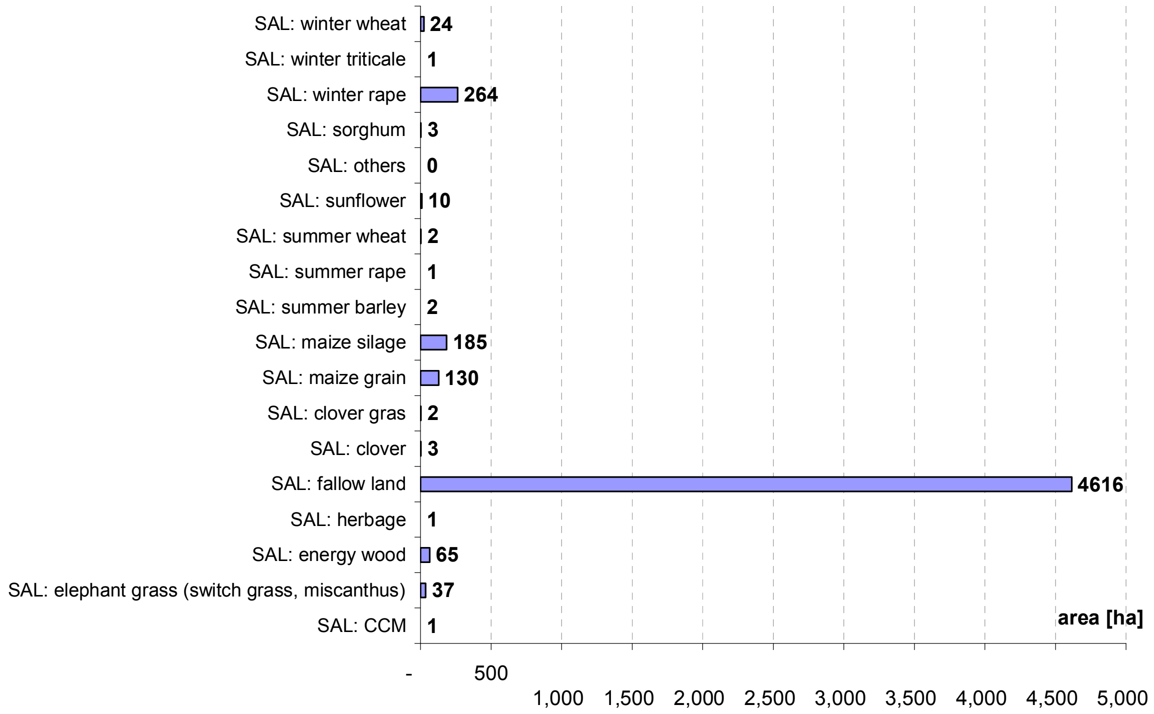


Figure 6: *Different kinds of crops used for energy production based on the cultivation at set-aside land in 2007 (Metschina, 2007); 1ha = 10.000m², SAL…set-aside land; CCM…corn cob mix*

Figure 6 shows different kinds of crops used for different energy products based on the cultivation at set-aside land in 2007 (Metschina, 2007). All together 730 ha of the total set-aside land available, are cultivated for energy production in 2007. The largest contributions are covered by maize silage and grain, used for biogas production (315 ha). Another area (264 ha) is cultivated with winter rape, used for the fuel production and the utilization in engines.

In future also energy crops like poplar and willow could be cultivated at set-aside land, which leads to a competition and multiple usage of these areas. 2007 only an area of 65 ha was cultivated with energy crops (woody biomass).

In addition, the real and actual potential of agricultural area in particular set-aside land, seems to be much smaller than stated in the study of Puchas. Resulting in updated information from Steirische Landwirtschaftskammer only approximately 4,600 ha (corresponding to the fallow) of set-aside land are available for energy production (Metschina, 2008) in relation to 12,681 ha in the year 2003 (Puchas, 2005).

Another large potential was stated for the biomass excess from grassland areas. BAL Gumpenstein published a study in 2003 where the productivity and the perspectives of the grassland were investigated. One finding of the study was that there are some centres of biomass excess which were pointed out in this study (Buchgraber et al., 2003). These centres were located mainly in the northern and western part of Styria. The energy equivalent for biomass based methane on the basis of excess biomass from grassland was calculated with 1,271,757 MWh/a (Puchas et al., 2005, pp 3-45).

Also this potential has to be considered critically regarding land competition with other energy products. Another point is the local density of the agricultural products and the complexity and costs of harvesting of the grassland potential, why the real potential in this category has to be investigated under consideration of more local conditions like e.g. hillside gradation and transport distances. These considerations will probably lead to a smaller potential compared to the stated potential in the study of Puchas.

In Figure 7 finally the concentration of different kinds of agricultural substrates of the discussed biomass based methane potential are pictured at different locations in Styria. Reduced amounts according to updated information were not taken into account in this figure. Locations with high concentrations can be considered as favoured future biogas locations, while locations with low concentrations are not preferred.

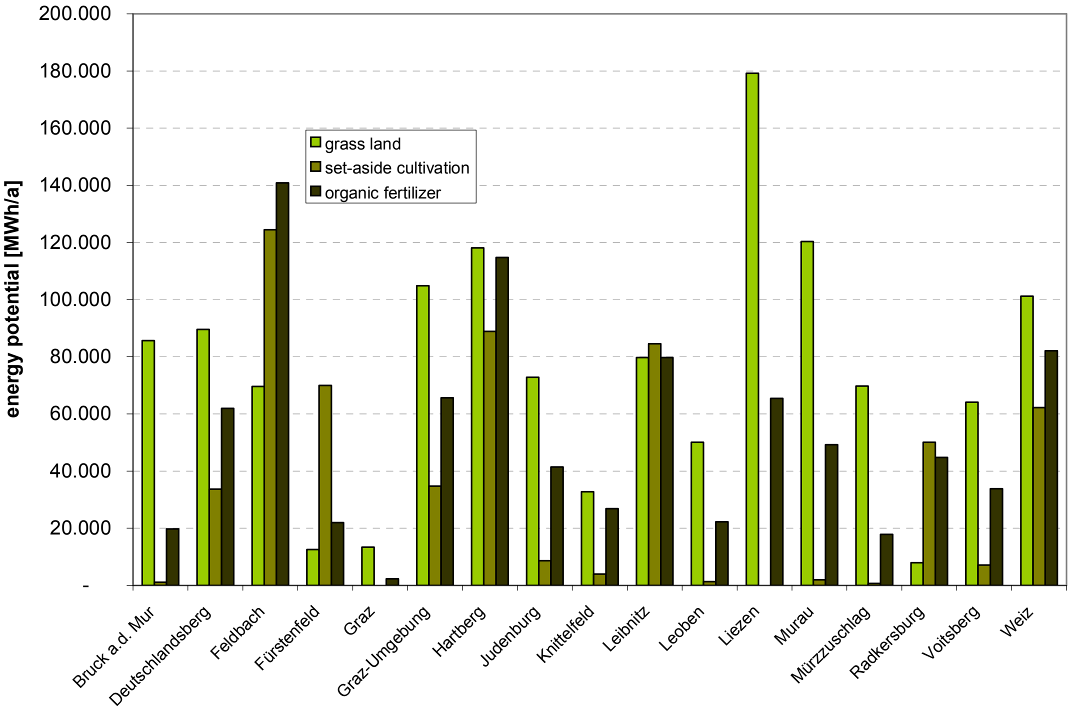


Figure 7: *Calculated biomass based methane potential for grass land, set-aside cultivation and organic fertilizer stated in MWh/a at different districts in Styria. Source Puchas et al. 2005*

2.2.3 Substrates from processing agro industries

Substrates from processing agro industries are substrates accumulated at production facilities for products made of agricultural raw materials. One of the most important representatives of these materials is brewer grain, which comes from beer brewing processes. Further substrates are the organic by-products from alcohol production, potato processing, sugar processing and e.g. fruit processing.

The most important representative for future biogas production seems to be brewer grain as well as organic residues resulting from beer brewing processes which have the largest share in this category (Puchas et al., 2005). Altogether an amount of 42,178 t/a organic residues was inquired from all essential brewery companies in Styria (Puchas et al., 2005, pp 2-15). This corresponds to an energy equivalent of 59,049 MWh/a (own calculations) based on methane yields of 130 m³/t w.b..

Updated information from the brewer industry (Rainer 2008) shows, that the main part of the brewer grain and organic residues are used as animal feed. These contracts are usually concluded for 5 years. The availability of theses residues will depend on the respective market conditions and prices within the next years.

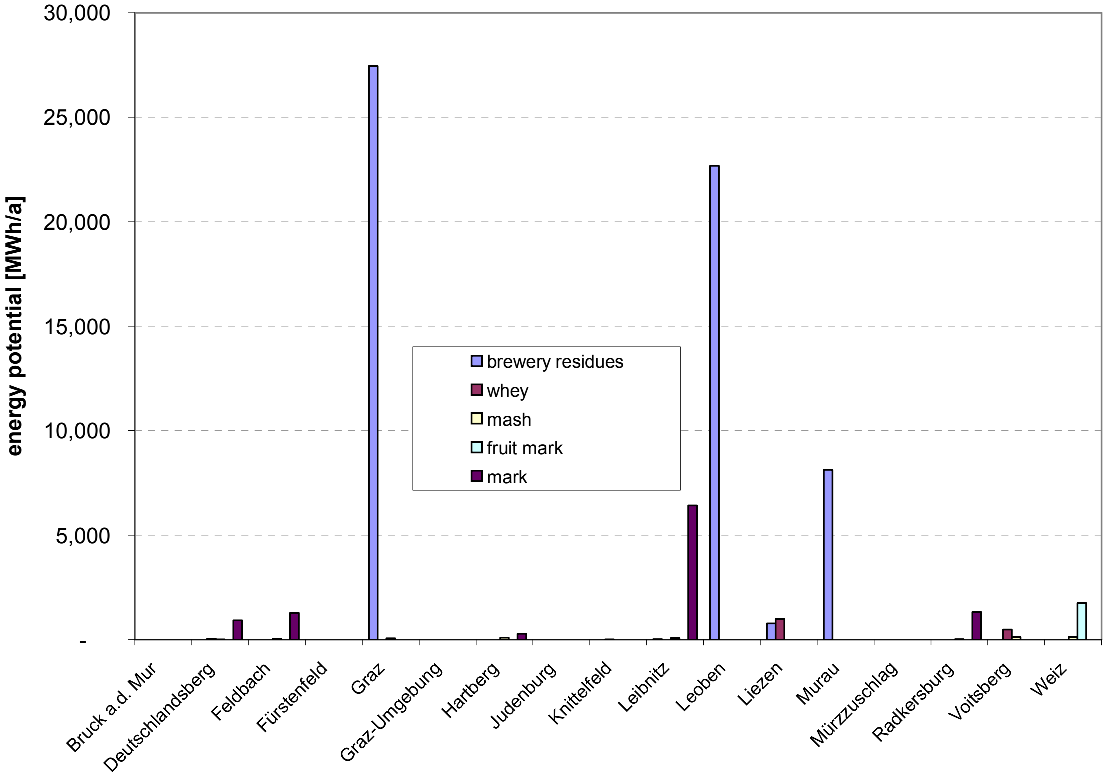


Figure 8: *Calculated biomass based methane potential for residues from agro industries stated in MWh/a in different districts in Styria. Source Puchas et al. 2005*

In total the contribution of wine marc in Styria reaches an amount of 10,220 MWh/a and the amount of whey contributes with 1,520 MWh/a to the total potential of biomass based methane. All other residues of the agro industry seem to contribute only a small amount to the total energy potential and are not discussed in the study more detailed.

Figure 8 shows that only residues from brewer industry essentially contribute to the biomass based methane potential. Further it can be concluded that there are only a few locations in Styria with high concentrations of feedstock.

2.2.4 Organic residues from households and communes

Organic residues from households and communes cover organic waste which is collected separately, leftovers from gastronomy business and expired food from e.g. food stores. Moreover separated grease from waste water treatment of different processes and vegetable residues/waste contribute to the potential for biomass based methane production.

Communal organic waste from households represents the largest fraction within this category. Based on the waste collection systems (FA 19D, AWV), the amount of separated collected communal organic waste for 2003 was 59,527 t/a (Puchas et al., 2005 pp 2-13). Additional organic fractions from different kinds of hotels and restaurants, hospitals and nursing homes, military facilities and other organic waste producing industry (excepting agro industry) were inquired with an amount of nearly 3,000 t/a. One difficulty regarding the inquiry of this kind of materials is, that no registration and recording measurement for this material streams exists. Therefore the actually amount could be much higher.

Altogether the energy content of these residues corresponds to an amount of 60,641 MWh/a (mainly caused by the organic waste fraction). At present the main share goes to communal and industrial biological waste treatment plants and is given to farmers and hunters for composting and animal feeding.

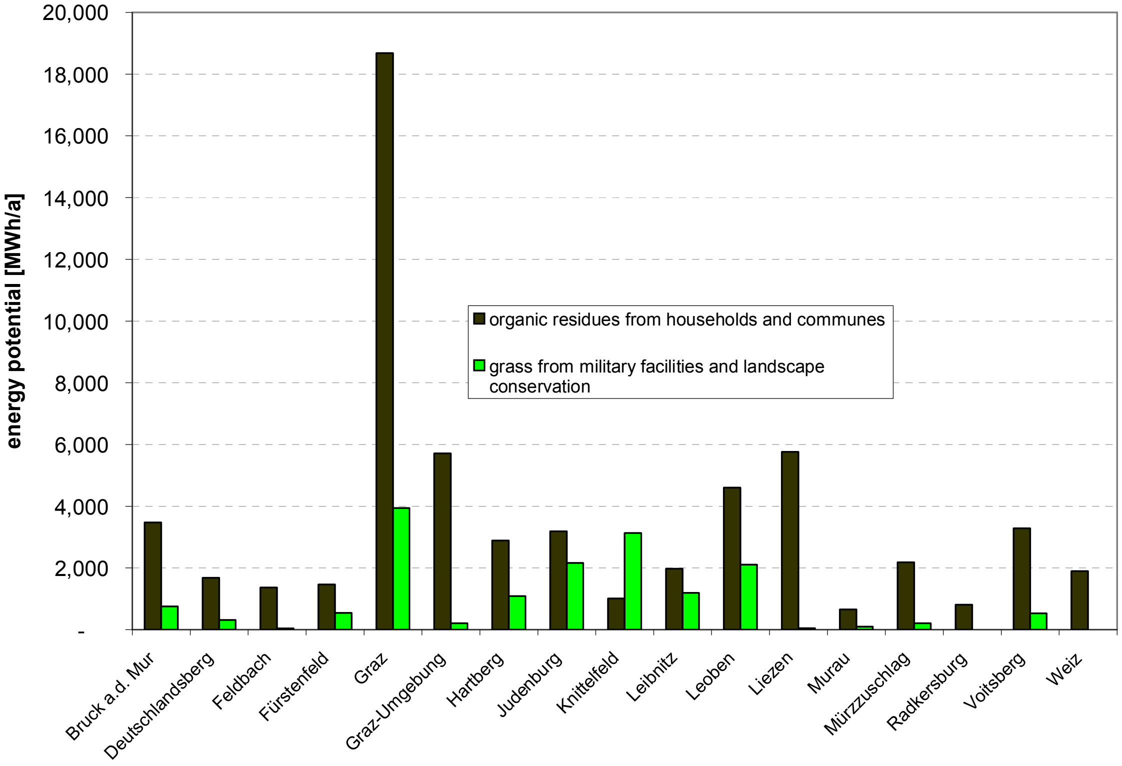


Figure 9: *Calculated biomass based methane potential for organic residues from households and communes stated in MWh/a in different districts in Styria. Source: Puchas et al.2005*

In principle the communal organic waste, which has high moisture content, should be preferably used for biogas production than for composting. One aspect, which has to be considered, is the logistic issue due to the disperse appearance of these fraction in Styria. Another important resource for biogas production is grass from military facilities and landscape conservation. This fraction is quantified with 23,568 t/a and corresponds to an energy equivalent of 16,376 MWh/a (Puchas et al., 2005 pp 2-15, 3-45). Figure 9 shows the concentration of organic waste potentials for biomass based methane in MWh/a at different locations in Styria.

2.2.5 Sewage sludge

Sewage sludge could also be used for the production of biogas. This kind of raw material was also used in the past for producing electricity and heat at sewage plants and can be considered as state of the art technology. Regarding the methane production and upgrading of the biogas based on sewage gas, the gas quality is still not investigated enough in Austria to assure continuous and steady operation after feeding the gas into the gas grid. Due to critical components contained in the communal waste, especially from cosmetics, the upgrading demand will increase to fulfil the requirements that are stated in the guidelines of the technical rules for gas quality (ÖVGW G33, 2006).

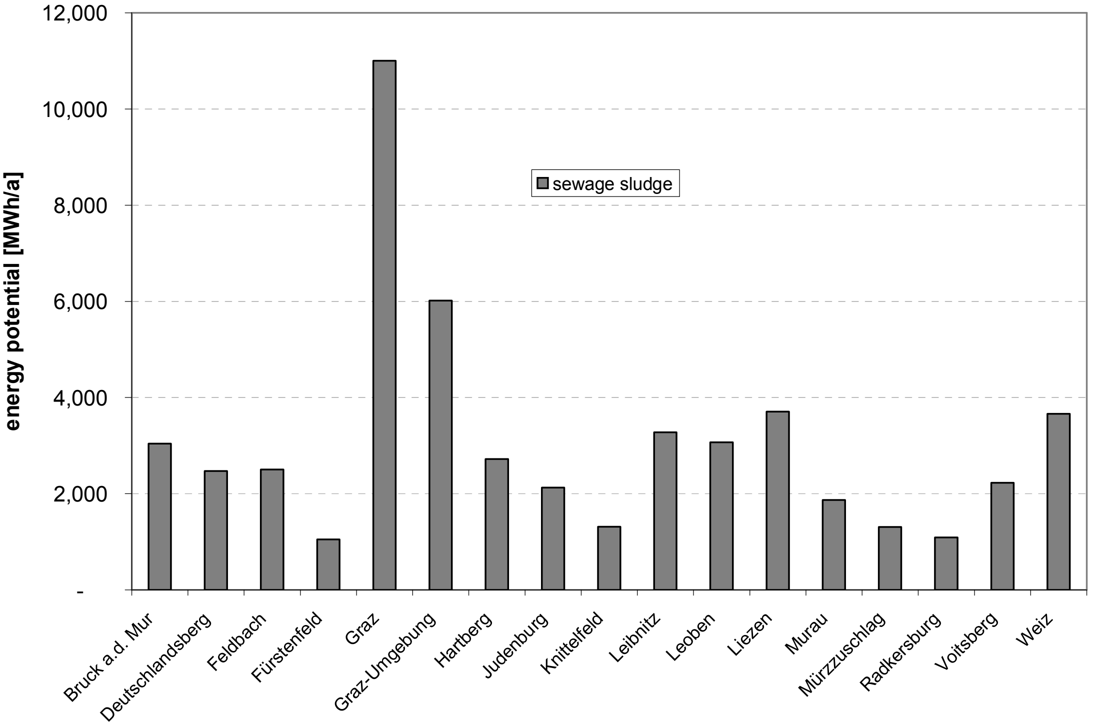


Figure 10: *Calculated biomass based methane potential for sewage sludge stated in MWh/a in different districts in Styria. Source: Puchas et al.2005*

Puchas published a total energy potential of 52,451 MWh/a for Styria (Puchas et al., 2005 pp 2-15, 3-45). Figure 10 shows the potential at different sewage plants in Styria. This potential is based on the population equivalent usually used for the waste water charge at sewage plants. Further the current use of sewage sludge based biogas for power production was not considered why this potential has to be investigated more detailed. In principle sewage plants demonstrate good conditions of technical infrastructure concerning biogas production. Therefore not only the sewage sludge as substrate should be taken into account for the decision concerning the erection of a biogas plant. Moreover the co-digestion of organic waste seems to be an interesting option for future biogas production.

2.2.6 Energy wood from forest

One of the central challenges related to the energy production from biomass is the sustainable supply of solid biomass. Solid biomass usually is discussed in relation with heat and power production and in addition in relation with the production of fuels for boiler applications like pellets and fuels of the second generation for automotive applications, the so called BTL fuels (biomass to liquid) like FT-fuels (Fischer-Tropsch fuels).

The production of biogas for gas net application (SNG…Syntetic Natural Gas) based on solid biomass is a new option and seems to be in an early stage of development, why detailed inquiries in particular for this energy application are not available so far. For Austria the demand on energy wood was calculated with 19 million solid cubic metres per year to fulfil the targets of the biomass action plan in Austria (AEA, 2006). Therefore the largest share was calculated for power production with 15 million solid cubic metres and 4 million solid cubic metres for heat production. The biomass demand for BTL (biomass to liquid) applications was considered for the year 2020 at first time and was appreciated with 1.1 million solid cubic metres for Austria. The amount of 19 million solid cubic metres energy wood for the year 2010 corresponds to an additional energy production in the field of power and heat production of total 144.5 PJ (40 TWh).

Related to Styria an estimation of roughly 10% of the demand of Austria can be calculated. Under consideration of a similar assumption related to the energy demand which was predicted for Austrian energy yields, the additional demand on woody biomass for heat and power production in Styria would be in the range of 2 million solid cubic metres.

Based on the forest inventory for the year 2000/2002 a forest increase of 8.534 million solid cubic metres per year and an utilization of 5.494 million solid cubic metres per year was stated (Amt der Steiermärkischen Landesregierung, 2003). This unused amount of nearly 3 million solid cubic metres wood seems to be available in Styria for energy applications. Under consideration of economical and sustainable aspects this potential represents only a theoretical value. Based on a comprehensive study of the Austrian biomass potential from wood resources in the year 2006, the potential of the not used forest increase could only be used in a range of nearly 20 to 30% under reasonably economical and sustainable conditions (Hirschberger, 2006). The inquiry showed, that big forest enterprises (bigger than 1.000 ha) have a degree of utilization of nearly 90% of the forest increase (which can be considered as maximum value), while small forest enterprises have only a degree of usage of 50%. Due to the structure of the forest enterprises in Austria the main part of the potential is given in the forest of small forest enterprises and can be assumed with the usage of additional 30% to reach the same degree of utilization as the big forest enterprises. Another reduction value considered in the study mentioned before was the usage of more significant wood assortments if additional mobilisation of wood from forest takes place. Consequently only a part of the additional usage can be used for energy applications. Therefore the study implied the previous distribution of the different assortments.

Based on a similar assumption for Styria with an unused potential of forest wood of nearly 2.9 million solid cubic metres, the real amount of additional usage from forest must be reduced to nearly 1 million solid cubic metres for energy applications (assumptions: potential of small enterprises is taken into account and 50% of this potential will be used for more significant wood assortments – see Table 2).

kind of ownership	**forest increase** 1,000 solid cubic metres	**forest utilization** 1,000 solid cubic metres
small forest ownership < 200 ha	5694	2926
enterprises > 200 ha	2429	2030
ÖBF	411	538
sum	***8534***	***5494***

Table 2: *Forest increase and utilization based on different sizes of enterprises in Styria, Source: Amt der Steiermärkischen Landesregierung, 2003; 1 ha = 10,000 m², ÖBF….Österreichische Bundesforste*

This rough calculation shows that there are big challenges to get additional wood based resources for all conventional energy applications. If there will be a potential for SNG production left in future is very difficult to answer at the moment, as long as these problems are not solved.

2.2.7 Summery – biomass based methane potential

Based on the potential of feedstock used within the biological conversion path a total energy equivalent for biomass based methane of nearly 2,800,000 MWh was calculated. With a biomass based methane production potential of approximately 2,600,000 MWh per year agricultural feedstock covers more than 90% of the total amount. The most interesting feedstock in this field is liquid manure with a biomass based methane potential of approx. 800,000 MWh/a. Compared to the potential of agricultural feedstock non agricultural feedstock have a rather low biomass based methane potential with nearly 70,000 MWh/a from agro industry, 77,000 MWh/a from organic residues from households and communities and approx. 56,000 MWh/a for sewage sludge.

For thermochemical produced biomass based methane a secured and adequate supply of woody biomass in Styria could not be predicted seriously. Under consideration of a mobilisation of 10% of available not utilized forest increase in Styria (100,000 solid cubic metres) a theoretical biomass based methane potential of approximately 245,000 MWh/a. could be achieved.

2.2.8 Future perspectives

2.2.8.1 Research activities concerning energy crops for biological conversion

At present there are 120 ha agricultural area used in Austria within research projects were the crop earning based on different kinds of cultivation is investigated. Main target is to increase the mass yield per ha but also to investigate the different influencing factors on the methane yield of each crop per ha. There are different kinds of crops under investigation. One of the basic information out of these projects was that there is a big difference in cultivation based on the requirements of crops for energy use and crops for foodstuffs and other applications. While for energy use mainly protein and fat contribute to the energy yield in an anaerobic degradation process, foodstuff applications follow different rules to fulfil their requirements to increase earnings.

Another important topic is the lignin content of the plants. Different kinds of crops have different properties related to the lignin and cellulose structure. A complex lignin structure affects the biodegradability of the organic substances and leads to lower energy earnings within the gas production process. Several investigations show, that longer harvest periods lead to increasing lignifications but on the other hand lead also to a higher yield of biomass per ha area. For increasing energy demand this means, that the increasing biodegradability has to be solved by new technologies, which enable degradation for these materials. Different kinds of technologies are still under investigation.

The results also showed that the amount of mass yield depends on a lot of local conditions. These are climate conditions, soil conditions and many other local parameters.

Another conclusion was, that the yield of biomass per ha increases with longer harvest periods. This also leads to lower water contents of the plants (see also Figure 11). This on the other side makes new harvesting technologies necessary because e.g. maize with water contents lower 60% can not be ensilaged.

Recapitulating there are many local things that have to be considered and there is lot of research work necessary in future to ensure the increase of biomass and energy yields for energy crops.

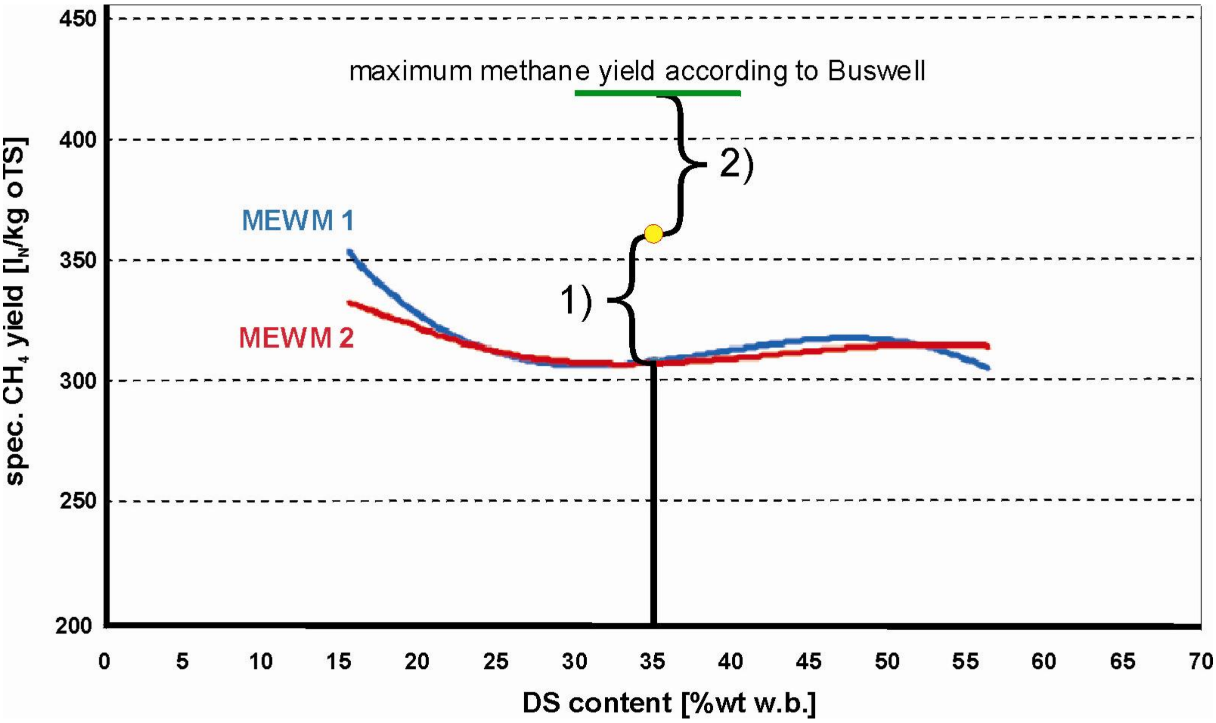


Figure 11: *Calculated methane yield of two different cultures of maize, affected by the dry mass content of the plant. MEWM…methane energy content model, source: Amon, 2007.*

Explanation: 1…additional specific methane yield potential available through increased biomass yields due to new cultures, 2…additional specific methane yield potential available with improved technologies that increase the degradation efficiency

Figure 11 shows the different affects on the methane yield based on a calculation model (MEWM…methane energy content model) for two different cultures of maize. Lower dry mass concentrations occurred at longer harvesting periods and optimised cultures could lead to an increase of methane of up to 53 l/kg oTS. Another additional methane potential is expected by the conversion of the presently technical not degradable components. This could be available with more efficient conversion technologies and represents an additional potential of 58 l/kg oTS. Under consideration of the ongoing research activities to meet these ambitious requirements, the methane yield for maize (approx. 305 l/kg oTS) could be increased in total up to 30 – 40 % to a value of 420 l/kgTS (see Figure 11) in future.

2.2.8.2 Research activities for biomass mobilisation

Ongoing activities in Styria are e.g. the development of a business segment called "Waldbiomasseversorgung-SÜDOST" through utilization of non active wood.

In this project the forestry associations in Carinthia, Styria and Burgenland have developed strategies to significantly increase the usage rate from the current level of approximately

62%. Professional business structures with comprehensive ranges of services, from the purchase of standing timber to expert support for targeted groups of forest proprietors, are a fundamental step towards achieving this goal. Accompanying trust-building measures such as the appraisal of the utilisation potential and the identification of the yield opportunities of an operation or the determination of quality assurance criteria for wood harvesting are indispensable success factors.

A theoretically useable energy wood potential of around 3.5 million solid cubic metres per year is available in the forests of the region covered by the project. The critical question is, however, how much of this quantity can be brought to market under sustainable conditions and within which time frame? Many aspects, such as ownership structure, usage habits, forestry equipment and know-how, economic success, ecological assessment, forestry counselling and the availability of a range of forestry services should all be taken into account. All factors considered it is clear that producing and marketing energy wood is only possible in combination with the mobilisation of all types of round timber production and that only a part of the statistical potential is actually realisable. To achieve this goal, considerable investments in the extension of technical harvesting capacities as well as a sufficient number of skilled personnel will be necessary.

2.3 Local gas grid conditions in Styria

The gas grid in Styria can be divided into three layers of gas ducts, depending on the pressure level of the grid section. Layer 1 covers the part of the grid needed for the transport and transit of gas in Styria with a pressure level of 70 to 120 bar. Layer 2 covers the whole part of the grid needed for distribution with a pressure level higher than 6 bar and finally layer 3 contains the distribution network with a pressure lower than 6 bar. Layer 1 is used for transport and transit exclusively. Layer 2 and 3 are an option for the injection of biomass based methane, depending on the capacity of the affected duct.

Beside a high gas quality required, the dimension of the duct and the consumption capacity of the grid must be large enough to carry the volume of gas that should be injected.

In particular the consumption in summer should excess the amount of gas that is injected to ensure a continuous operation of the production and utilisation of the produced biogas. These conditions have to be taken into account to meet optimised technical and economical conditions.

The gas grid in Styria is not expanded over the whole area (compare Figure 12). Therefore relevant locations related to the availability of the feedstock have to be considered critically regarding grid conditions, due to a missing gas grid or to small dimensions and missing capacities of the grid.

The plant (gasification or biogas plant) for the production of upgraded biogas should be located as near as possible to the feedstock available (to large distances for transport of the input materials will prevent an economic operation) and on the other hand the distance to the point of delivery should be as short as possible also.

These boundary conditions limit the number of possible locations for the gasification, which requires large plants and a relative high quality of the woody biomass used to become economic, as well as for the production of biogas, which can be realised in a more flexible way, due to the variety of possible input materials and smaller plant sizes.

One affect of this approach is that the biomass potential located at regions without any natural gas grid infrastructure (e.g. Murau) can practically not be used as short term potential for biomass based methane production due to the fact, that the feedstock has to be transported to the production plants via long distances (>50 km). Usually the production plant should be erected enclose the prospective injection point. Otherwise long injection pipes would lead to higher investment costs and consequently to higher specific production costs.

The maximum permissible distance to the production plant and the maximum permissible length of injection pipe to the prospective injection point follows individual economic conditions and were not investigated within this work.

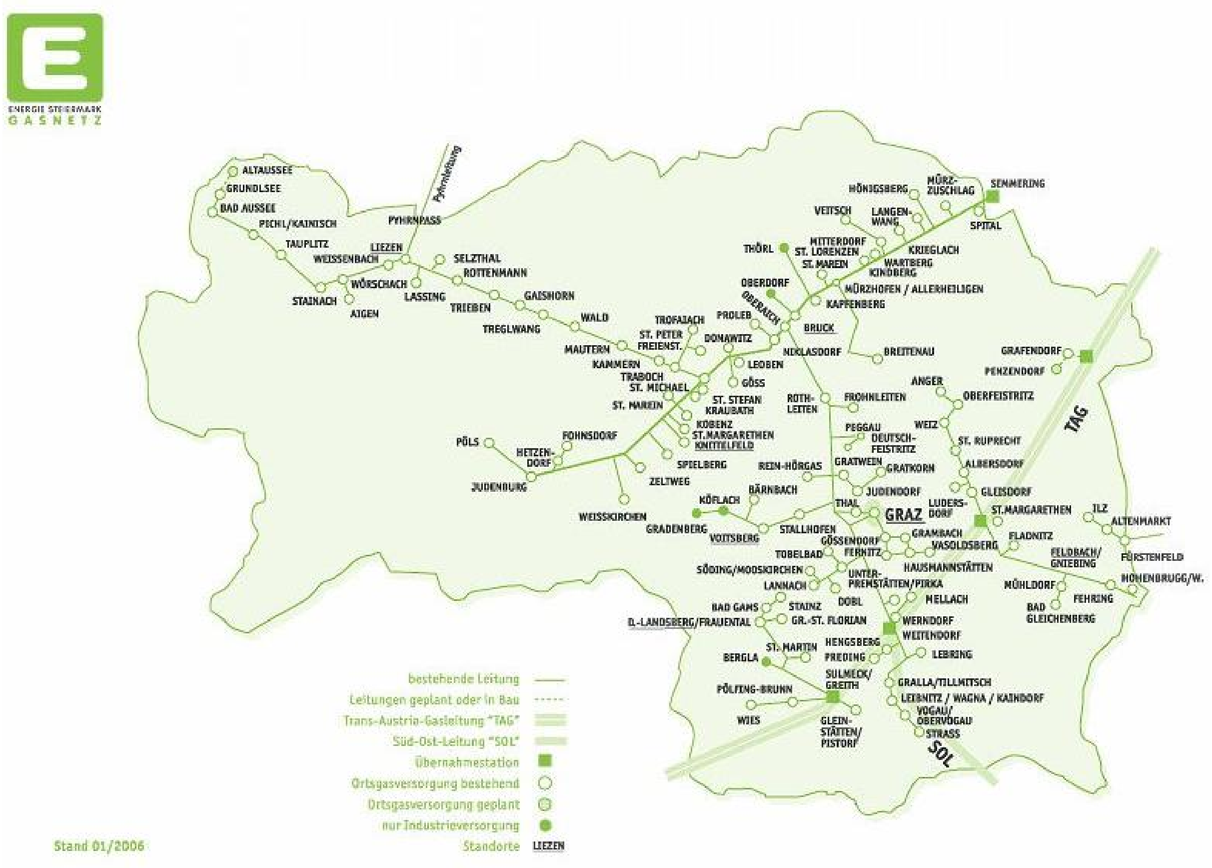


Figure 12: *Natural gas grid in Styria; Source: Gasnetz Steiermark GmbH*

Considering the mentioned parameter the evaluation of possible locations for such plants is still ongoing subsequent to this work.

3. Technical evaluation of biomass conversion

3.1 Biological conversion process

3.1.1 Process description

To produce bio-methane in the first step an anaerobic digestion process is necessary to ensure the degradation of organic substances.

Biogas is formed by anaerobic digestion of organic substances, which is solely driven by the activity of bacteria (Wellinger et al., 1991). This biological process is the key part of the whole process and can be described in four stages, shown in the picture below.

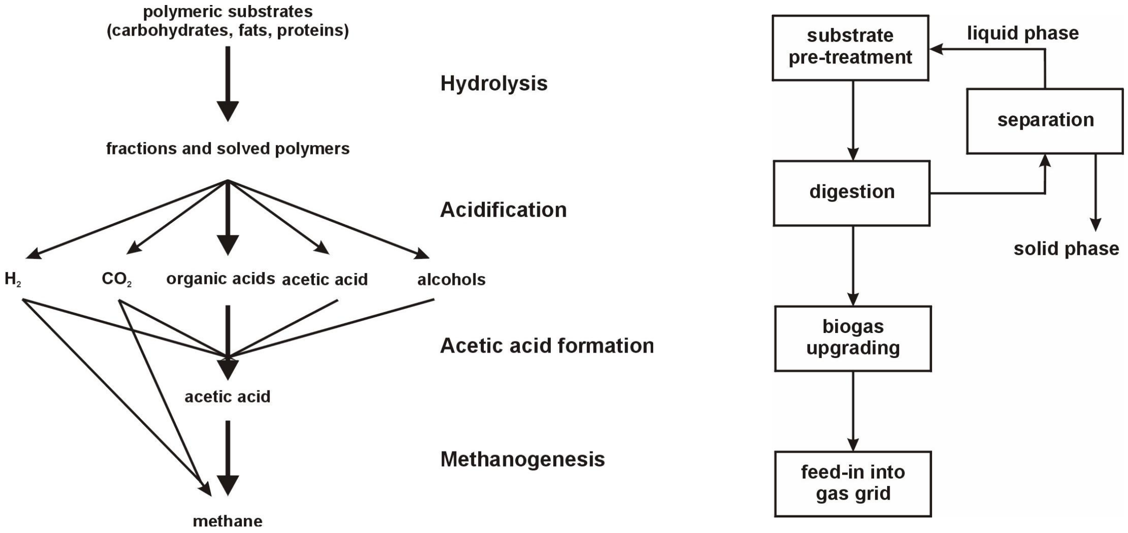


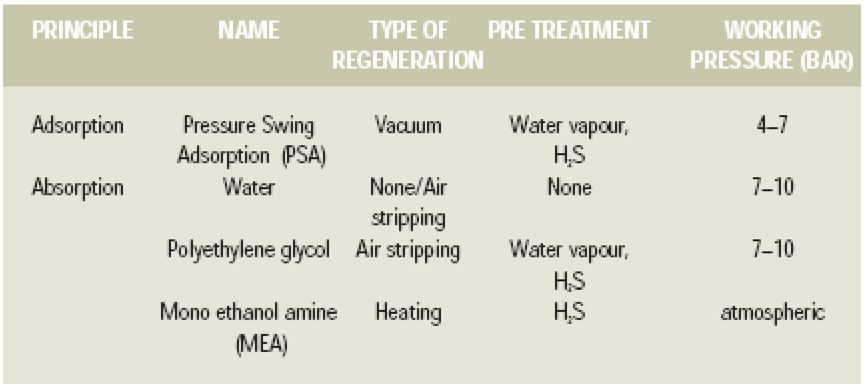
Figure 13: *Steps of anaerobic digestion (Böhnke et al., 1993); simplified flow sheet of biogas production*

In the digestion process the organic substances are fragmented by three different groups of bacteria. Within the first step - also referred to as hydrolysis - complex matter like proteins, fats and carbohydrates are split by so called enxoenzymes. This step is the slowest and determines the speed of the whole reaction. Within the second step - the acidification - the product will be degraded to acids like acetate, propionate etc. and lactic acids, alcohol and to a small amount hydrogen and carbon dioxide. Afterwards another degradation takes place in step 3. The products are acetate acid, hydrogen and carbon dioxide. This step is the most difficult step from the thermodynamic point of view because energy is needed to run the reaction. Within the final step methane bacteria degrade the acetic acid to methane.

The produced biogas primarily consists of methane (50% -70%) and carbon dioxide (30% - 50%) as well as small amounts of hydrogen sulphide (up to 1%) and ammonia (NH_3). Trace amounts of hydrogen, nitrogen, carbon monoxide, saturated or halogenated carbohydrates, oxygen, and siloxanes are occasionally present in the biogas. In addition, the produced gas is saturated with water vapour. Typical process temperatures are between 30°C - 42°C (under mesophile conditions) and 45°C – 60°C (under thermophile conditions).

Depending on the gas quality, the produced biogas can be used for many applications according to natural gas. The utilisation of biogas in internal combustion engines is the most common application so far and requires relative low gas quality standards. In case of Styria, requirements concerning gas quality for biogas used for natural gas grid applications are very high. The gas quality standard is specified in the gas quality directive ÖVGW G33. Therefore upgrading devices have to be connected to the process (see also Figure 13).

One of the main tasks of upgrading systems is the removal of carbon dioxide. There are several different commercial methods for reducing carbon dioxide. Most common are physical and chemical absorption or adsorption processes. Other techniques, which are still in development respectively and have reached demonstration status are for example membrane separation and cryogenic separation (Persson et al.2006).



PRINCIPLE	NAME	TYPE OF REGENERATION	PRE TREATMENT	WORKING PRESSURE (BAR)
Adsorption	Pressure Swing Adsorption (PSA)	Vacuum	Water vapour, H_2S	4–7
Absorption	Water	None/Air stripping	None	7–10
	Polyethylene glycol	Air stripping	Water vapour, H_2S	7–10
	Mono ethanol amine (MEA)	Heating	H_2S	atmospheric

Table 3: *General data for absorption and adsorption processes; Source: Petersson et al. 2006*

Table 2 shows typical operating conditions of the most common upgrading systems used. Each technique has to be carefully selected and adjusted to the local conditions given at the respective plant (feedstock used, gas quality, net conditions, availability of waste heat etc.). In principle the processes are well known from large scale gas cleaning devices.

After the biogas has been upgraded to the required gas quality standard, the product gas has to be conditioned and measured to be able to feed the gas into the natural gas grid (see Figure 13).

3.1.2 State of technology

Biogas digestion

The anaerobic digestion of manure and sewage sludge is the most common application of biogas production performed in many small agricultural digesters and sewage plants. Today, biogas production is a well tested technology for wastewater treatment and upgrading of biowaste from households and agriculture. Due to implementation of attractive feed-in tariffs for green electricity in different countries and the utilisation as transport fuel, the efficiency of the plant becomes more important and standardisation especially for agriculture substrates and organic waste increases.

***Figure 14**:* *Building site of a biogas digestion plant park based on renewable resources in Güstrow (Germany)*

Depending on the conditions of the feedstock used and the plant size many digestion systems are available on the market and can be considered as state of art technologies. In Austria there are 335 plants in operation. In Styria there are 45 plants in operation producing green electricity and district heat based on different kinds of feedstock (E-Control, 2007). In general all biogas plants in Austria are performed as combined heat and power plants to produce green electricity. In Germany approximately 4000 plants have been erected so far (Bundesministerium für Umwelt, Naturschutz, und Reaktorsicherheit, 2007).

Figure 14 shows the building site of a biogas digestion plant park based on renewable resources in Güstrow (Germany). The plant uses maize silage, liquid manure and grain for a biogas production capacity of about 10,000 m³/h and demonstrates the largest biogas plant worldwide so far. The start of operation is scheduled for summer 2008.

Biogas Upgrading

For transport fuel and gas grid applications biogas needs to be upgraded to reach a high methane content and a high gas quality. For this purpose a couple of technologies is available at the market which are based on different process technologies. The processes themselves follow thermodynamic and physical laws and are well known from other gas conditioning processes e.g.: O_2 production or gas cleaning applications in the chemical and gas industry. In principle all common processes, which are used for biogas upgrading are well developed for applications with gas volume streams of 1,000 m³/h and more.

One of the main problems is that there are only a few companies producing such upgrading systems for small scale applications. Thus these technologies are very expensive and support in maintenance and operating of the system is rather bad. The problem that has to be solved is, to develop upgrading systems for smaller biogas units in the range of 50 to 300 Nm³/h at moderate costs.

Only two technologies with sufficient experiences are currently on the market especially in Sweden and Switzerland. These technologies are pressure swing adsorption and water scrubbing.

Each of these technologies has its special opportunity at different application sites and under certain biogas conditions so that many aspects have to be taken into account for the technology choice.

Figure 15: *Biogas upgrading systems, water absorption system: source: Haase 2007, pressure swing adsorption system: Carbotec, 2007*

Sweden has the largest number of upgrading systems (32 plants) which are mainly based on the water scrubber systems and adsorption techniques. The first plant was erected twelve years ago in 1996 (Petersson, 2008). Another country with a quite respectable number of upgrading systems is Switzerland. Also Germany started with the erecting of upgrading systems in 2006 (motivated by the renewable energy law). One well known example is the plant in Pliening. This plant has an upgraded gas capacity of 490 m³/h. In Austria there are only 3 upgrading pilot respectively demonstrations plants in operation so far. In Upper Austria OÖ Ferngas AG realized the first biogas upgrading plant in Austria. The upgrading system was connected to an existing biogas plant based on poultry litter. The capacity of upgraded biogas is 6 m³/h, the used technology is based on an adsorption technique.

Another project realised by the Salzburg AG in Eugendorf was started in 2008. The biogas produced using grass silage as substrate is upgraded (~30 m³/h) and injected into the gas grid. Afterwards it can be used as regenerative fuel at local fuel stations, where it is offered as so called “Bioerdgas”.

A further Austrian project was realized at an existing biogas plant in Lower Austria (Bruck an der Leitha) in 2007 by a consortium of OMV Gas International GmbH, Wien Energie Gasnetz GmbH, EVN AG, Technical University of Vienna, and Energiepark Bruck/Leitha. The upgrading system is based on a new developed membrane separation and has a capacity of 100 m³/h (methane equivalent).

The main reason why there are not more plants with upgrading systems is, that Austria has no economic incentive (e.g. funding) for this kind of applications so far. From the technical point of view the quality of natural gas in Austria is very constant and has high standards so that the upgrading systems used in other countries have to be adopted to the local requirements.

3.1.3 Technological challenges

In principle the technology used along the chain to produce bio methane is state-of-the-art. There are some optimisation demands within the different parts of the system which should lead to higher efficiencies and lower costs.

Regarding the digestion system itself, there is a demand on technologies which enable a higher organic conversion ratio. Especially biogas plants based on feedstock with suboptimal quality standards such as feedstock with a certain amount of lignin tend to a bad conversion performance. In that case different decomposition and pre-treatment systems as well as hydrolysis systems are still in discussion (Wieselburg, 2007).

Another very important issue is the after-treatment of the produced digestate. Due to restrictions concerning the feed material on the one hand and the restriction for nitrogen concentration on the other hand high disposal cost and/or long transport distances for the application as fertilizer have to be accepted. Therefore technologies for upgrading of digestate are necessary to solve the problem of the transport of high water quantities.

In the case of biogas upgrading systems, the performance of the different plants has to be optimised, especially in the field of direct methane emissions. Another important issue is the energy efficiency, which should be reduced as low as possible.

3.2 Thermochemical conversion process

3.2.1 Process description basics

To produce a substitute natural gas (SNG) from solid biomass, which is the main source for this conversion path, it is necessary to convert the organic mass of the biomass into a synthetic gas by a gasification process in a first step.

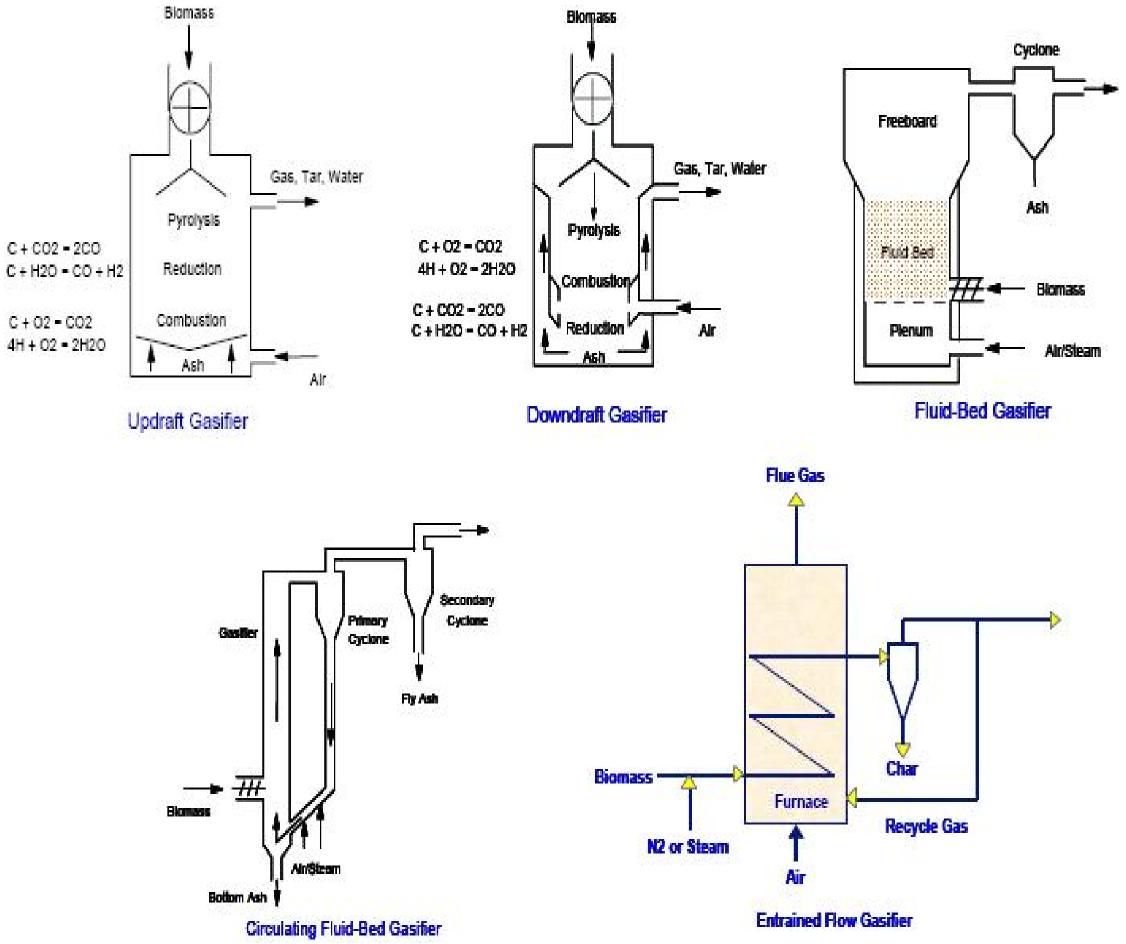


Figure 16: Different kinds of gasification reactors

Various gasification processes are still under development all over Europe. Several demonstration plants are in operation but the break through of this technology has not been reached up to now.

Gasification is a thermal conversion process that uses a gasification agent which contains oxygen. Oxygen can be put into the process by using air as conversion agent but also can be put in by using steam. Depending on the gasification agent different kinds of technologies are under investigation, which have different advantages and disadvantages.

Figure 16 shows different kinds of gasification reactors, which have there individual properties concerning different kinds of fuel, size of plant and gas composition needed. Updraft gasifier and downdraft gasifier can not be used for SNG production.

The process itself takes part at reduction conditions at temperatures up to 800 °C. The different stages and most important reactions are as follows:

- 1 Heating and drying < 200°C
- 2 Pyrolytic decomposition (200 – 500°C)
- 3 Oxidation (> 700°C)
- 4 Reduction (> 800°C)

Which of the stages 3 and 4 is running first depends on the type of the reactor used. The interstage gas produced within this gasification process has the following typical range of producer gas composition (see table 4):

CH_4 vol - % dry	**CO** vol - % dry	**CO_2** vol - % dry	**H_2** vol - % dry
9 - 11	**22 - 25**	**20 - 22**	**38 - 40**

Table 4: *Typical composition of the producer gas of a gasification process of the main components (Hofbauer, 2008)*

For synthetic gas applications and therefore SNG production it is necessary to convert the H_2 and CO rich product gas into CH_4 – the second step to get a natural gas substitute. This will be done by the most important reactions shown below:

$$CO_{(g)} + 3H_{2(g)} \xrightarrow{\text{catalyst}} CH_{4(g)} + H_2O_{(g)}$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

$$2CO \rightarrow CO_2 + H_2$$

Carbon monoxide and hydrogen are the most important components in the producer gas for the SNG process. A catalyst e.g. nickel, supports the SNG reaction to convert CO and H_2 into CH_4 and H_2. One important issue is that the quality of the gas affects the catalyst in an essential way. Sulphur and chlorine compounds are strong catalyst poisons and have to be removed before entering the methanation reactor.

After the methanation reaction the gas has the following typical composition (see table 5).

CH_4 vol - %	**CO_2** vol - %	**H_2** vol - % dry	**N_2** vol - % dry
40	**47**	**4**	**8**

Table 5: *Typical composition of the producer after the methanation process of the main components (Hofbauer, 2008, results from long duration test in Güssing 2007)*

Table 5 shows the composition after the methanation rector. To fulfil the requirements of the gas quality standards for natural gas grid applications another upgrading system has to be connected to reach a methane content of >97 % (G33, 2006). For SNG applications a total energy efficiency of up to 70% is expected from wood chips to methane.

Figure 17 shows a principle flow sheet of the process from the biomass feeding to the SNG feed in facilities (ECN, 2006). On the one hand there are two main reactors necessary to convert the organic matter into the desired gas quality.

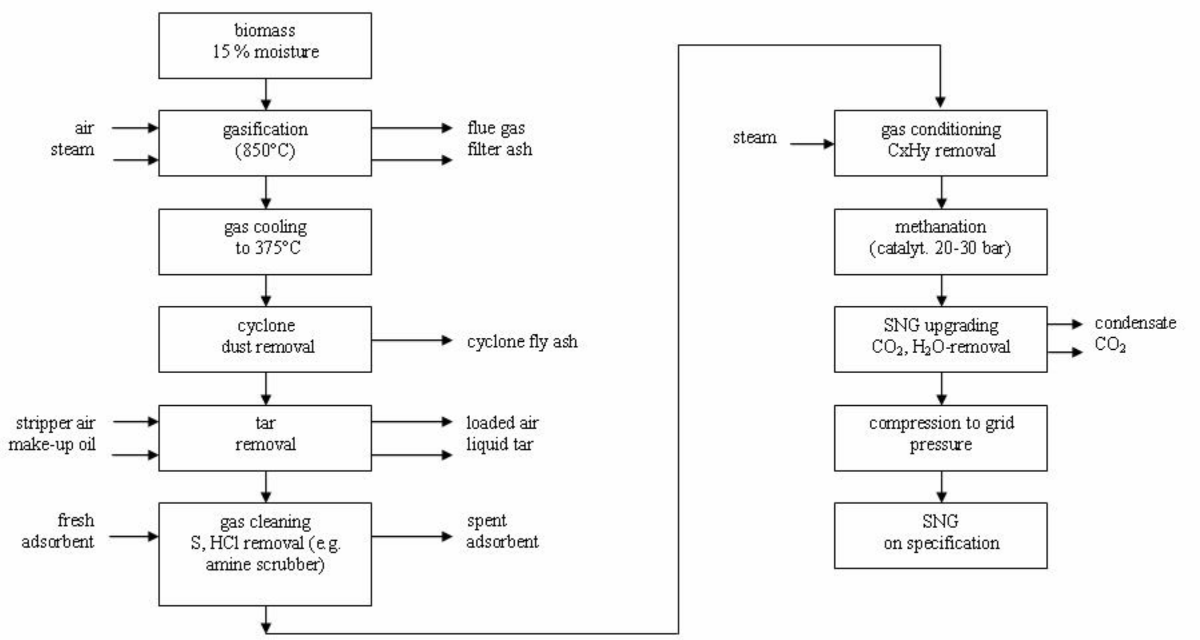


Figure 17: *Process sheet of SNG production, source ECN, 2006.*

Both, gasification reactor and methanation reactor need to have certain operating and fuel conditions to achieve the requirements of the produced intermediate gas product. Therefore different reactor concepts are still investigated.

Beside the two reactor facilities many gas cleaning facilities have to be installed to clean the different intermediate gas products from hazardous components. The gas treatment in the integrated bio-SNG line-up comprises tar removal technology, sulphur and HCl removal technologies as well as a product gas cleaning and upgrading unit to reach the quality required for gas grid applications. The removal of tar components is usually done by filter technologies and scrubbers with organic liquid solvents. In the demonstration plant Güssing for example RME is used as solvent (Hofbauer, 2008). Sulphur and chlorine compounds are strong catalyst poisons and have to be removed especially in case of SNG production before the gas enters the methanation reactor. This is done for example based on adsorption techniques. Typical adsorbents used are ZnO filters to remove the H_2S and activated carbon guard bed to remove all remaining trace impurities (ECN, 2006).

The final step, before the gas can be fed into the grid, is an additional upgrading step, which is comparable to the upgrading of biogas discussed in chapter 3.1. One additional aspect is that the requirements related to the cleaning efficiency are higher compared to biological produced biogas, because more carbon dioxide has to be removed. Finally it can be concluded that this conversion path demonstrates a high complexity as well as a high level of reaction and upgrading steps to convert woody biomass into a gas product for natural gas grid applications.

To fulfil all these technical requirements under reasonable economic conditions appropriate plant capacities are necessary. Experts discuss plant sizes larger than 20 – 30 MW, for poly generation systems (electricity, heat and transport fuel) up to 150 MW fuel input (Hofbauer, 2008; ECN, 2006). This will lead to additional requirements concerning availability of wood based feedstock and appropriate plant location.

3.2.2 State of technology

Gasification process based on biomass

A comprehensive inquiry concerning gasification projects based on biomass shows, that there are only a few projects worldwide dealing with this kind of energy production. From the commercial point of view definitely no plant could be found performing an economic operation so far. The following examples give a rough overview about the current situation of these conversion technologies:

Technology/ Project Name	Location	Energy Product	Feed stock	comments
CARBO V (CHOREN) entrained bed gasification. 29 MW fuel imput	Germany Freiberg	Sun Diesel	50% wood chips, 20% tree cut 30% Miscanthus	start of operation 08. 2008
Viking (two stage gasification)	Denmark	Electricity production	Wood chips	Start of operation 2002, (2,300 operating hours, problems with corrosion and clinker deposition → 2005 reconstruction, currently investigation of methanol production
Harboore, 4MW fuel input	Denmark	Electricity production	Wood chips	Operation since 1993, 70,000 operating hours
Güssing (fluidised bed reactor) 8 MW fuel input	Austria Güssing	Poly generation: electricity, heat, SNG pilot plant, FT-fuel	Wood chips moisture 20 – 30%	Operation since 2002, More than 30,000 operating hours
Värnamo / CHRISGAS Project pressurised Bioflow BMG IGCC process for CHP (9 MWth and 6 MWe)	Sweden Värnamo	Electricity production	Refuse derived fuels (fluff, flake and pellet)	out of operation

Table 6: *Examples of different projects in the field of biomass gasification*

The main differences between existing fossil fuel gasifiers for syngas production and biomass gasification are the content of minor components in the product gas (impurities), the content of the major components (H_2, CO, etc.) and the necessity of an air separation plant for oxygen production. No existing gasification technology meets all the demands to produce bio-syngas in one process step (Zuberbühler et al. 2006).

Most of the demonstration plants mentioned in Table 6 have still technical problems of different kinds within the specific process steps or have been taken out of operation due to economical reasons.

The Austrian project in Güssing seems to be one of the most advanced technologies in this field. At the demonstration plant in Güssing a dual fluidized bed reactor based on steam gasification is installed. After some problems during the first operating years and some adjustments on the plant, the plant reaches operating hours of up to 7,000 hours per year (IV2S-Portal, 2007). Since the start up in 2002 in total 30,000 operating hours were achieved so far. The produced synthetic gas is used in a combined heat and power module to produce electricity and district heat.

Apart from some sporadically demonstration projects it can be concluded that gasification of biomass is still not a commercial technology.

SNG production

SNG production based on biomass is in a very early state of development so far. Only a few organisations are engaged with this kind of technology. For SNG production also the right selection of the gasification process is essential. Further high quality requirements of the methanation process lead to high technical requirements on the cleaning devices.

In Europe there are in principle 2 groups engaged with SNG pilot projects: ECN (energy centre Netherlands) and a consortium of TUV (Technical University of Vienna), PSI (Paul Scherer Institute Switzerland) and CTU (Conzepte Technik Umwelt AG, Switzerland). In both cases only experiences of pilot plants are available so far. At the gasification plant in Güssing a pilot plant for the production of not upgraded SNG (10 m³/h) is in operation for nearly one year. A first demonstration plant with a capacity of 100 to 200 m³/a is under construction. The erection of the plant was started in 2007, In the middle of the year 2008 the start of operation is scheduled. More information about the performance of this technology is expected after the first year of operation. Related to a midterm realisation based on market conditions, BIO-SNG is not expected to be available within the next 10 to 15 years.

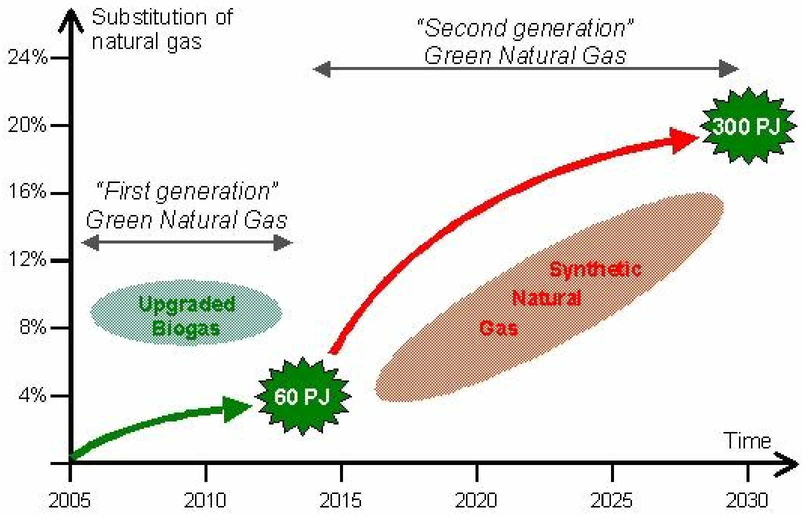


Figure 18: *SNG for heat production – the Dutch point of view (ECN, 2006)*

Also ECN is working in this field. The situation there is quite similar. Figure 18 shows the Dutch point of view regarding the production of biogas for natural gas grid applications. In the Netherlands the SNG production is expected not before the year 2015 – 2020.

3.2.3 Technological challenges

Gasification:

In general, the technical hurdles include handling of mixed feed stocks, high-pressure solids feeders and ash discharge systems, real-time monitoring and timely control of critical gasifier, operational parameters, minimising tar formation in gasification, hot gas particulates, tar, alkali, chlorides and ammonia removal, heat recovery, conventional gas clean-up, waste water treatment and effluent management as well as process scale-up. It should be noted that none of the technical advancements in the investigation of individual unit operations or unit processes guarantee a successful scale-up and application of these innovations, primarily for first-of-a-kind demonstration projects (Babu, 2005).

SNG production

Relating the hurdles regarding the SNG production the experiences based on the pilot plants are too poor to make serious predictions.

In principle there are many hurdles on upstream connected instruments to fulfil the requirements for the methanation process that have to be solved first. Which way of energy conversion for the syngas will be used, can not be predicted. Therefore different energy concepts for liquid fuel (Fischer-Tropsch fuel), gaseous fuel (SNG) and heat and power production are under investigation.

4. Production costs of bio methane - economical evaluation

First it has to be pointed out, that in the case of feeding the gas into the grid both conversion paths needs subsidies to be competitive to the current energy market based on natural gas at the moment in Austria! In Germany for example the green electricity law allows to accept green electricity tariffs based on power production with biogas that is taken from the natural gas grid. This biogas can be fed into the grid at any net point in the grid and can be taken out at a different point where conditions for combined heat and power production are appropriate. This leads to increasing interest for biogas feed-in projects due to good economical conditions. The Austrian green electricity act does still not allow this kind of approach, why biogas taken from the natural gas grid competes with natural gas respectively the low energy prices of natural gas in the range of 2,5 € - 3 Cent/kWh.

The following chapter discusses different cost affecting parts of the two conversion paths to get an impression about the main influencing factors. For the thermochemical path it is very difficult to get serious costs due to the lack of experiences, why this result only can be observed as rough estimation.

4.1 Costs based on different kinds of feedstock

Figure 19 shows some calculated typical production costs for bio-methane based on a study performed in order of BGW in Germany 2006 (Wuppertal Institut, 2006). Therefore different kinds of feedstock were assumed. The comparison shows, how the use of different feedstock can affect the total production costs within the different categories (feedstock, biogas conversion, upgrading, feeding-in). The calculations are based on German market conditions and can not be applied for Styrian market conditions as well, but the results will be in a similar proportion in Styria and offer a good basis to discuss different production cost affects.

The examples in Figure 19 represent 4 biogas plant models with different kinds of feedstock and different production capacities for each model. The different costs stated include costs for feedstock, biogas conversion (capital and operating costs), upgrading (capital and operating costs) and finally for feed-in (capital and operating costs) as well as transport within the gas grid. The first example represents a biogas plant with mainly liquid manure used as feedstock.

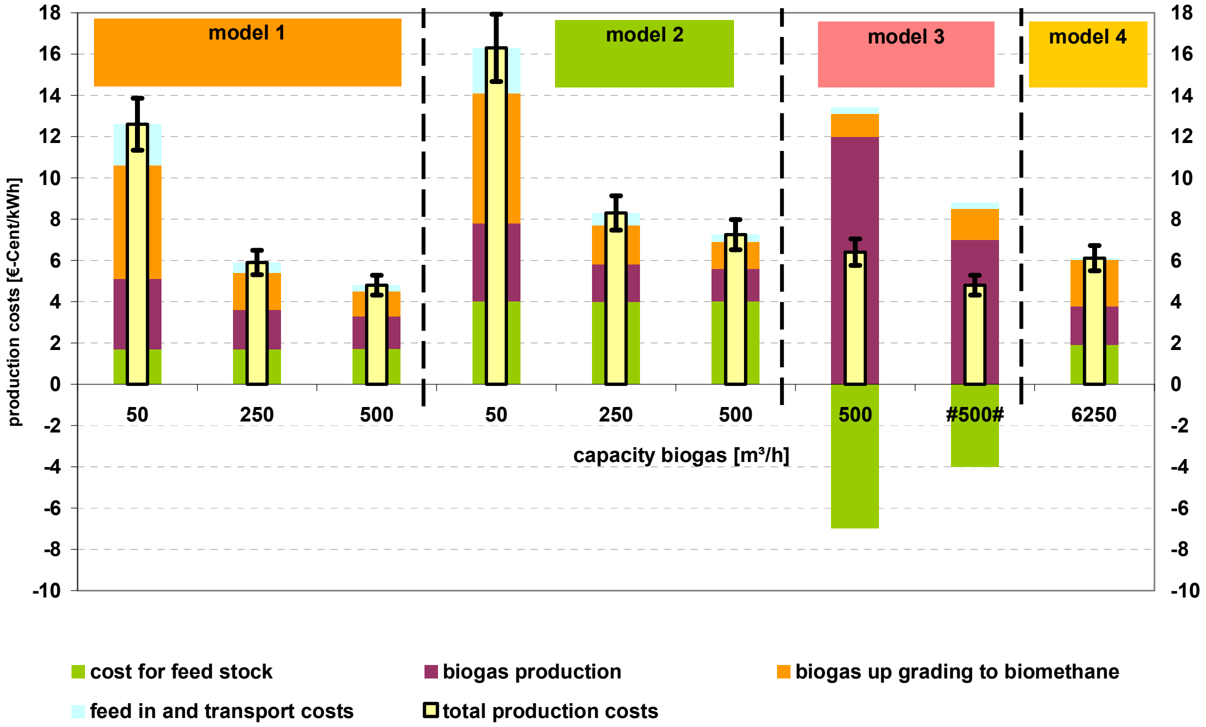


Figure 19: *Specific biomethane production cost for varied production models at different production capacities (Wuppertal Institute, 2006); #500# … own calculated "fictitious example"*

	model 1	model 2	model 3	model 4
feedstock	90% liquid manure 10% maize silage	10% liquid manure 90% maize silage	100% bio waste	100% wood chips
Price of feedstock	liquid manure: 0 €/t w.b.	maize silage: 30 €/t w.b.	bio waste: - 35€/t w.b.(#-20€/t w.b.#)	wood chips: 61,5 €/t w.b.
Methane content of the biogas	57%	53%	62%	36,8%
Total investment				
50 m³/h	1,334,320 €	1,358,869 €		
250 m³/h	2,401,351 €	2,366,112 €		
500 m³/h (#500#)	3,428,171 €	3,587,854 €	16,580,884 € (#10,000,000 €#)	
6,250 m³/h				20,976,725 €
Operating costs:				
50 m³/h	52,798 €	52,086 €		
250 m³/h	87,115 €	80,460 €		
500 m³/h	110,285 €	108,996 €	1,195,738 € (#900,000 €#)	
6,250 m³/h				1,136,450 €
demand based costs				
50 m³/h	105,725 €	153,417 €		
250 m³/h	335,416 €	546,394 €		
500 m³/h	633,803 €	1,062,828 €	-1,626,637 € (#-1,000,000 €)	
6,250 m³/h				6,302,569 €

Table 7: *Summary of assumptions for production cost calculation of different models in figure 19; operating hours: 8000h/a, life time 15 years, source: Wuppertal Institute, 2006.*

As it can be seen feedstock costs for model 1 are relatively low with nearly 1.5 – 2 €-Cent/kWh compared to the second example were renewable resources are used mainly. All other cost pools mainly depend on capital respectively investment costs and therefore increasing gas production leads to lower specific production costs due to increasing economy of scale. In comparison with the first and second model in Figure 19 specific costs for biogas conversion, upgrading and transport costs are in the same range, because plant components are quite similar for the first and the second model. With increasing capacities (500 m³/h) total production costs of 5 Cent/kWh can be achieved with liquid manure. The third model represents a plant with communal waste conversion.

The structure of the costs is different to the examples before, because the upgrading of the waste feedstock to be fed into the digester has high costs and is energy intensive. On the other hand the feedstock itself causes no costs, but gathers waste disposal revenues whereby the higher investment costs can be compensated. For the example in Figure 19 total production costs of 6.3 Cent/kWh can be achieved at a capacity of 500 m³/h. The second example (fictitious own calculation) of the waste based model shows clearly the opportunity to optimise total production costs by using lucrative and easy convertible waste as it can be grease separator or other homogeneous and liquid waste fractions. The affect will be that costs for biomass upgrading can be reduced but also revenues will be lower.

The fourth model was calculated for BIO-SNG (thermochemical production). Therefore high capacities are necessary (6,250 m³/h) to achieve production costs in the same range as stated at the biological conversion paths (model 1-3). Another interesting point pictured out in Figure 19 are the high specific costs for gas upgrading devices (see also chapter 3.2)

5. Conclusions

The biological conversion path uses a wide range of different organic feedstock which has in principle rather high water content and meets the requirements to be easily degradable to achieve a high conversion ratio. Typically materials within this category are materials with high protein and carbohydrate content that can be found in agricultural and communal waste residues as well as in agricultural energy crops (renewable resources) for example maize silage.

For thermochemical produced biomass based methane respectively BIO-SNG primary wood based feedstock is used with rather low moisture content (15% -30%) and certain specifications to fulfil the requirements for the gasification process to achieve high conversion efficiencies of 70%.

Excepting the use of agricultural areas, which can be used for the production of energy crops for biogas plants and energy wood for thermochemical conversion as well, it can be concluded that the available and appropriate feedstock in Styria do not compete in connection with the two investigated biomass based methane production paths.

The availability of the substrates for the biological conversion process follows different market mechanism and depends on specific local conditions. In case of agricultural feedstock Styria has a high potential of raw materials. The methane based energy potential for renewable resources like biomass excess from grassland and energy products cultivated on set-aside land are in a theoretical range of 575,000 MWh/a respectively 1,270,000 MWh/a.

Under consideration of high fluctuating availability of set-aside land and sometimes low density of feedstock from excess of grass land as well as difficult and expensive harvesting, conditions will lead to a much lower availability in fact.

The most interesting potential in the field of agricultural substrates are liquid manure with a biomass based methane potential of approx. 800,000 MWh/a. Further there are some interesting locations with high feedstock concentrations which allow large scale biogas plants and poor transport requirements.

Compared to the potential of agricultural substrates non agricultural substrates have a rather low methane based energy production potential with nearly 70,000 MWh/a from agro industry, 77,000 MWh/a from organic residues from households and communes and approx. 56,000 MWh/a for sewage sludge. Apart from this point, there are some interesting locations with high densities of each of these substrates, which would allow erecting large scale biogas plants with a biogas production > 500 m³/h. These districts are in particular Graz (plus Graz neighbourhood) and Leoben (plus Bruck) where the conditions for co-digestion seem to be quite well.

For the thermochemical conversion path the mobilisation of solid woody biomass is an existing challenge in lot of other energy production areas in particular to provide the recourses for the existing and planed power plants based on biomass. Due to the fact that for thermochemical conversion high plant capacities (> 6,000 m³/h) and high quantities of biomass (> 6,125 kg/h w.b.) are needed, a secured and adequate supply of such a plant in Styria can not be predicted seriously.

Under consideration of an energy efficiency of 70% (ECN, 2006) based on the feedstock energy and a biomass potential of 10% of one million solid cubic meter from not utilized forest increase a theoretical biomass based methane potential of approximately 245,000 MWh/a. (2,450 kWh/solid cubic meter) could be achieved.

From the technical point of view the production of upgraded biogas along the biological chain can be stated as state of the art technology. There is some optimisation demand within the components to achieve higher plant efficiencies and lower operating costs. Another opportunity is the mature technology and the moderate process conditions that enable plant sizes in the range of 500 m³/h biogas production capacity with moderate investment costs, which are advantageous relating to the local feedstock and gas grid conditions in Styria.

Biomass based methane production based on thermochemical conversion respectively SNG production seems to be not available under commercial conditions at the market within the next 10 to 15 years. The process is very complex and there are many problems still not solved in the pre-connected gasification step. In addition the demand on upgrading devices is much higher than in the case of methane rich biogas from biological conversion. At the moment there are only a few pilot and demonstration plants in operation.

From the economical point of view most effecting parameter for production costs of biomass based methane along the biological conversion path are the feedstock costs and costs for feedstock upgrading demands. Therefore the utilization of liquid manure as feedstock achieves the lowest production costs for biomass based methane of approximately 5 € Cent per kWh. Energy crops like maize silage generates feedstock costs of >30€/t w.b. which leads to production costs of > 7 €-Cent/kWh. In the case of bio wased based methane production, high investment and operating costs of bio waste upgrading can be compensated by gathering waste disposal revenues.

Thermochemical produced biomass based methane needs high capacities (>6,250 m³/h) to achieve production costs in the same range as stated at the biological conversion path. The most cost affecting parameter are investment and operating costs for gas upgrading devices.

Compared to an average energy price for natural gas of 2.1 – 2.6 €-Cent/kWh (price for industrie – e-control, 2007) it can be pointed out, that in the case of feeding the biomass based methane into the natural gas grid both conversion paths needs different amounts of subsidies to be competitive to the current energy market at the moment in Austria.

Based on the results mentioned before and under consideration of short term realization the process based on the biological conversion path should be selected to be investigated more detailed to develop a concept for realisation. Therefore in the first step available organic residues and organic waste should be taken into account for the evaluation of possible plant locations. The secured availability and moderate long term market conditions will be one of the most crucial factors of success.

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