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Nordic Energy Research

Mapping the Baltic Sea Region on Technology Developments – compilation of questionnaires

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Summary

Nordic Energy Research is responsible for Task 5.1 ”Mapping the Baltic Sea Region on Technology Developments” in the Interreg project Bioenergy Promotion, which is a joint project of 33 participating partners from ten countries around the Baltic Sea: Belarus, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland and Sweden. In order to acquire bioenergy-related input for the Baltic Sea Region, Nordic Energy Research has submitted a questionnaire to some of the participating partners. However, the questionnaire form was short and fairly simple, and the feedback was relatively limited. Therefore, Nordic Energy Research has asked ÅF-Engineering AB for additional information.

The objective of this report has been to review, analyse and compile the results from the questionnaires and complement, when necessary, with statistics and ÅF in-house expertise of bioenergy-related developments in the Baltic Sea region. The focus of the questions in the questionnaires was on research and development projects as well as demonstration projects in the bioenergy field in the region. Additionally, the questions included visions of the bioenergy situation in the year of 2020 and 2050.

Of the 33 participating partners, 12 national contact organizations were given the questionnaire. Out of these 10 responded. Therefore, the material in this report cannot be considered to give a complete mapping of the situation in the Baltic Sea region. In addition, it should be noticed that the answers only reflect the view of the interviewee and not necessarily the general view in the specified country, field or partner institution.

When describing the present situation, the bioenergy field has been divided in three general areas: (1) biomass fuel supply and logistics, (2) upgrading of biomass, and (3) conversion technologies. Each of these three general areas is also divided in subareas, and the examples from the questionnaires have been classified in each of these subareas. This classification illustrates that regarding fuel supply, most reported research projects as well as demonstration sites are focusing on cellulose and lignin-rich raw materials. Very limited activities have been reported on starch and oil-seed crops. Regarding the conversion technologies, the research and demonstration is focused on combustion of biomass and to a limited extent digestion for biogas production. Furthermore, it is also evident from analyzing the results from the questionnaire that there is a great difference between the different countries within the Baltic Sea region. For example, Estonia’s respondent is anticipating waste-fired power plants in 2020. However, this technology is already commercial and very wide spread in e.g. Sweden. Another example is the biogas production where markets are established in Germany, Sweden, and Denmark, but in Estonia, Lithuania and Latvia, only a very small emerging market exists, and in Belarus, there is no production of biogas at all. Moreover, a similar situation can be seen for biodiesel (FAME) production where Germany has large production plants, while the markets have only started to emerge in most of the other countries. This

differentiated situation is also reflected in their vision of the bioenergy situation in 2020 and 2050.

There seems to be considerably differences in the challenges that the different countries are facing in the future. Some countries lack the infrastructure needed for developing their bioenergy sources, while others lack the technology or the knowledge. Because of this, there is a great potential for fruitful cooperation between the countries in the Baltic Sea region. Even so, the extent of development being made will be driven by the political ambitions on national as well as on intergovernmental level. Other factors affecting the possible development are the availability and competition for bioenergy sources, as well as the measures for energy efficiency will be implemented in the different countries.

1 Background

Nordic Energy Research is responsible for Task 5.1 “Mapping the Baltic Sea Region on Technology Developments” in the Interreg project Bioenergy Promotion. The target groups for task 5.1 are governmental representatives, R&D institutes, technology providers and users, and entrepreneurs.

The Interreg project Bioenergy Promotion is a joint project of 33 participating partners from the ten countries around the Baltic Sea: Belarus, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, and Sweden. The project aims at promoting the development of a sustainable bioenergy sector in the Baltic Sea Region.

To acquire bioenergy-related input for the Baltic Sea Region, Nordic Energy Research has submitted a questionnaire to the project participants. However, according to Nordic Energy Research the questionnaires are short and fairly simple, and the answers are as a result limited. Nordic Energy Research has therefore asked ÅF-Engineering AB to summarize the results from the questionnaires and add additional information.

1.1 Objective

The aim of this report is to present the status on the following subjects:

- general aspects of bioenergy
- bioenergy details (availability and utilization) in the Baltic Sea Region
- a vision of the technology for the years 2020 and 2050

The report has mainly been produced based on inhouse knowledge at ÅF. The questionnaires that were sent out to the selected partners have been used to give examples of research projects, demonstration sites, and pilot plants within these countries. The answer from the questionnaires has also been used when making a vision of the technology in 2020 and 2050.

This report does not represent a complete mapping of the development for bioenergy technology in the Baltic Sea region. Rather, it comprises selected examples from the participants in the Interreg project Bioenergy Promotion. Hence, specific answers in the questionnaires only reflect the view of the respondent and are not necessarily the general view in the specified country or partner institution. The answers given by the interviewees are presented in Enclosure 3.

1.2 Participants

Of the 33 participating partners in the Interreg project Bioenergy Promotion, 12 were asked to answer the questionnaire. 10 of these replied, though a few of them did not respond to all questions. Therefore, the material in this report cannot be considered to give a complete mapping of the situation in the Baltic Sea region. A list of the respondents and their affiliation can be seen in Enclosure 1.

1.3 Mapping the Baltic Sea Region on Technology Developments

Renewable energy sources are important tools for the mitigation of climate change. Bioenergy, which may be considered CO_2-neutral during a full harvesting cycle is one of the main contributors to renewable energy. At present, bioenergy provides about 9.6 % percent of the global primary energy supply[1].

Statistics for bioenergy consumption presented in this report are at the earliest from the beginning of 1990. During the period around 1990, the issue of climate change was first being addressed on a global scale, leading to an increasing utilization of bioenergy in some countries.

The Rio Summit in 1992 is often considered as the starting point for global efforts to work against human induced climate change. At this conference, the United Nations Framework Convention on Climate Change (UNFCCC) was established. The parties of the UNFCCC acknowledged that change in the Earth´s climate and its adverse effects are a common concern of humankind. This far, the most important step for mitigation of climate change under the UNFCCC has been the creation of the Kyoto Protocol where binding emission targets for emissions of greenhouse gases (GHG) are defined for a number of industrialized countries listed in the Annex B of the Kyoto Protocol[2].

The Kyoto Protocol entered into force in 2005 and its first commitment period is between 2008 and 2012. During the first commitment period the countries under the Kyoto Protocol that have agreed to reduce their emissions of greenhouse gases are obligated to reduce their emissions by an average of five percent compared to the emission levels that they had in 1990. If an Annex 1 country would fail to reach its target it will get a 30 percent higher obligation for the exceeding part during the second commitment period.

The first commitment period ends in December 2012, and the second commitment period is due to start immediately afterwards. Well before that, a strategy for a new agreement is needed, so that a gap in the process can be avoided. The 15th Conference of the Parties (COP) has recently been taking place in Copenhagen. This is the meeting for the countries that are Parties to the Convention, and the goal was to agree on a post-2012 climate commitment. Such agreement could not be reached, though some positive results were achieved from the meeting. Thus, the process is continuing. It is important to note that the Kyoto Protocol also required several years of additional discussion after the COP 3 in Kyoto before it could enter into force.

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[1] IEA Renewables Information (2009 Edition)

[2] The countries with binding emission targets are listed in Annex B of the Kyoto Protocol.

2 Bioenergy in the Baltic Sea Region Today

There is a great difference in how far the countries of the Baltic Sea Region have reached in terms of developing bioenergy solutions. Table 1 shows the biomass production per country in the Baltic Sea Region in year 2007.

Table 1. Total energy consumption and bioenergy production per country in the Baltic Sea Region. Sources: Eurostat and www.bioenergypromotion.net

Country	Population (million)	Total final energy consumption (TWh)	Primary production of biomass (TWh)	Share of biomass and waste in gross inland energy consumption
Belarus	9.7	N/A	N/A	N/A
Denmark	5.4	183	30	14.2 %
Estonia	1.4	35	9	9.8 %
Finland	5.3	309	86	19.3 %
Germany	82.5	2446	257	6.5 %
Latvia	2.3	51	18	24.6 %
Lithuania	3.4	58	9	8.4 %
Norway	4.7	219	15	4.9 %
Poland	38.1	712	55	4.8 %
Sweden	9.2	389	114	19.4 %

This chapter is subdivided into Fuel supply and logistics, Upgrading of fuels, and Conversion of fuels. The first part, Fuel supply and logistics, consists of: forest fuel, energy crops and agricultural residues, as well as oil-seed crops. The second part about upgrading of fuels includes pellets, briquettes, powder production, pyrolysis, and torrefaction. The third part, Conversion of fuels, consists of combustion for heat and electricity, biogas production based on digestion, FAME (i.e. biodiesel) production through esterification, ethanol production based on fermentation, and transportation fuel production based on thermal processes. Each chapter starts with a general description of the current status, followed by a discussion of the examples from the questionnaires and ÅF in-house expertise.

The bioenergy value chain can be divided in different ways. Figure 1 illustrates what kind of biomass (e.g. forest fuel, energy crops, etc.) that can be used as a raw material in different conversion technologies described in this chapter. The primary use of wood fuels in the energy sector is for the production of district heating and electricity. More recently, wood fuels are also utilized as raw material for transportation fuels. Since wood fuels consist of cellulosic material, they may be converted to alcohol. They can also be gasified for the production of a variety of highly upgraded products.

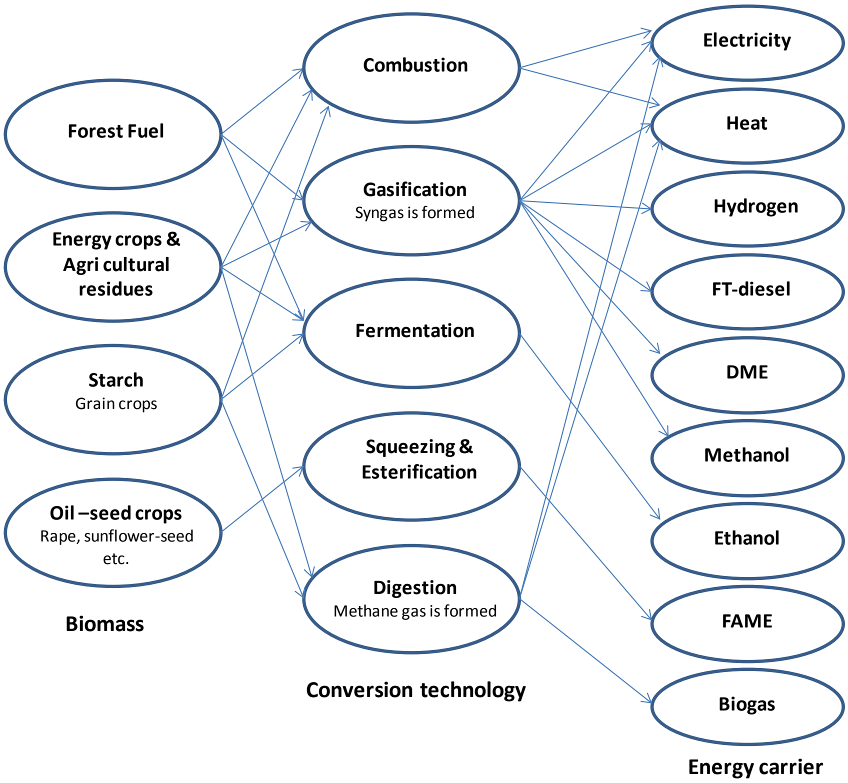

Figure 1. An overview of conversion technology and energy carrier from a variety of biomasses

Fermentation of starch, digestion of residues, as well as squeezing and esterification of oil-seed crops are techniques that are commercial on the market. Today, there is no commercial production of ethanol from cellulosic biomass but there is extensive research going on in the area. Gasification followed by conversion of the gas to final transportation fuels is another technique that is being developed. At present, there are a variety of processes available both for the biomass gasification step and for converting the raw gas into a valuable product such as transportation fuel but gasification is currently expensive and the costs need to decrease substantially in order to enable competition with other commercial fuels on the market. Furthermore, for some of the transportation fuels being produced by gasification of biomass, e.g. DME, there are no systems for the supply of the fuel available, nor any vehicles with engines that are adapted to DME.

The projects described in the questionnaires from the participating countries in the Baltic Sea Region are listed in Enclosure 2. Each project has been classified according to the areas defined in Figure 1 (e.g. Forest Fuel, Energy crops, Combustion etc.).

2.1 Fuel supply, Bioenergy sources and logistics

Biomass, such as wood, energy crops, etc. are CO_2 neutral fuels during a full harvesting cycle, since the amount of CO_2 released during combustion of biomass corresponds to the amount of CO_2 absorbed from the atmosphere at the growth of the biomass. These fuels may thus help to reduce the greenhouse effect if they are replacing fossil fuels and bioenergy may also contribute to a sustainable energy system by being a renewable energy source. However, biomass as a fuel used for heat and electricity production or for production of transportation fuels have a number of properties that differentiate it from fossil energy sources such as oil, natural gas, and coal (See Table 2).

For example, biomass is in its natural form solid, which has made it necessary to develop new handling systems for many applications. Biomass also has a higher content of oxygen than coal and thus a lower calorific value. In addition, most biomass has a high moisture content and a relatively high ash content, which reduces the calorific value even further. High ash content can cause problems during combustion (see chapter 2.3.1). Another problem with biomass is that the qualities of the fuel changes when stored, since physical, chemical and microbial processes begin, which lead to loss of material.

Table 2. Properties of biomass and some fossil energy sources,[3] [4]

Biomass	Net calorific value (dry matter and no ash content) [MJ/kg]	Moisture content [weight-%]	Ash content [weight-%] (dry matter)
Wood chips and sawmill residues	16-18	8-60	0.4-0.6
Wood residues	19-21	35-55	1-5
Wood pellets and briquettes	19-21	9-10	0.4-0.8
Willow	18-20	25-50	1-5
Grain	17-22	14	2-4
Reed Canary Grass	17-20	10-15	3-7
Straw	18-20	10-20	4-10
Hemp	19	15-75	1.6-6.3
Peat	19-27	38-58	2-9
Coal (Bituminous coal and Anthracite)	21.1-31.7	-	-
Crude oil	42.6-43.2	-	-
Natural gas	47	-	-

Research and development in the field of bioenergy sources and supply can generally be classified as focusing on (1) new harvesting techniques, (2) new sources for bioenergy and (3) increasing the yield when producing forest fuel, energy crops, or agriculture residues.

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[3] Strömberg B., Handbook of fuels (Bränslehandboken), 2005
[4] IPCC, Revised 1996 Guidelines for National Greenhouse Gas Inventories. Reference Manual (Vol. 3), Energy, 1997

New efficient harvesting techniques are described by the respondent in Finland. VTT (Technical Research Centre of Finland) is performing a project to increase the knowledge about production and handling technology for biomass fuels. R&D work is carried out in cooperation with fuel producers and suppliers, equipment manufacturers, district heating and power plants and other research organisations. They are working at VTT´s laboratory facilities as well as in practice, both in biomass production areas and district heating and power plants. The research on production technology of biomass fuels is focusing on fuel procurement, supply and handling technologies with the goal to develop more efficient machines and methods for solid biomass fuels. A part of the project is already finished, concerning Reed canary grass production and combustion technology. Forest fuel production technology will be developed during 2008-2010.[5]

Table 3 shows the primary energy production of solid biomass in the region between year 2004 and 2007.

Table 3. Primary energy production of solid biomass in the Baltic Sea Region [TWh per year]. Source: EurObserver

	2004	2005	2006	2007
Belarus	N/A	N/A	N/A	N/A
Denmark	14.0	14.7	15.0	16.8
Estonia	6.9	6.9	7.0	8.1
Finland	85.6	76.9	87.0	83.0
Germany	71.3	91.4	99.2	106.0
Latvia	16.2	16.2	18.5	17.9
Lithuania	8.2	8.6	8.8	8.5
Norway	N/A	N/A	N/A	N/A
Poland	47.2	50.0	53.4	52.9
Sweden	86.8	92.3	96.9	98.2

Some of the most important biomass resources in the region are described below. The end products from bioenergy systems can be used for transport, heating, and electricity supply.

2.1.1 Forest fuel

Most of the countries in the Baltic Sea Region have a large domestic supply of forest-based fuels and also a large forest industry. However, one important exception is Denmark which is a more agriculture based country regarding biomass supply.

The driving force for harvesting forest is usually for utilization in the wood timber industry, which normally have a relatively high ability to pay: The part of the wood that is regarded to have the highest value is used in the wood timber industry. The second most valuable part of the wood is used as raw material for the pulp and paper industry. Finally, the part of the wood which is rejected by the wood timber industry and the pulp and paper industry is commonly used for energy purposes. This means that it is the stem wood with a diameter smaller than 5-10 cm and other residues such as tops, branches, bark, and stumps that are used for energy purposes. In addition to the wood that has no major industrial uses, other types of forest fuels are

[5] Questionnaire, Finland, Research project #3

industrial by-products, such as saw dust and shavings. It is easier to consider the fuel´s quality characteristics during the first stage of handling in the forest if the fuel is directly derived from the forest (primary forest fuel). For fuels that stem from by-products from the forest industry (secondary forest fuel), the raw material is actually planned for a purpose other than energy utilization. Hence, it is the industry's primary product that determines the quality on the fuel.

A forest fuel project called "Wood for energy - a contribution to the development of sustainable forest management (WOOD-EN-MAN)" has been carried out in Lithuania. It was lead by the Danish Forest and Landscape Research Institute and was a R&D project under the EU 5th Framework Programme. It focused on sustainable use of wood-based biomass resources for energy, the aim being the further development of sustainable forest management in Europe. This also included aspects such as biodiversity and socioeconomic and economic effects. End-user-products will be based on integrated ecological, biological and socioeconomic research. Central topics was 1) Ecosystem nutrient vulnerability, 2) Environmental effects of wood-ash recycling, 3) Insect biodiversity and 4) Socioeconomic and economic effects at management and policy levels.[6]

The Latvian research project "Energy wood resource assessment, forest thinning technologies and cost of the operations in 20-40 years old forests" aimed at promoting utilization of small dimension trees and harvesting residues from pre-commercial and commercial forest thinning in biofuel production for local district heating systems and further processing into pellets and briquettes. The project covered manual and motorized harvesting technologies, costs and quality of the operations as well as it was the first attempt to evaluate, how much biofuel that can be produced by forest thinning in Latvia.[7]

Skogforsk, in cooperation with LSFRI Silava has conducted a project in Latvia. The name of the project was "Forest energy from small dimension stands, "infrastructure objects" and stumps". Latvian State Forests (LVM) has conducted trials and investigations on extraction of forest residues for bioenergy from clear felling, and was interested in proceeding with further investigations including forest energy from other sources such as; young trees in pre commercial thinning operations, "infrastructure objects" such as road sides, ditches etc, and stumps after clear felling. Skogforsk and LSFRI Silava were appointed to carry out field studies of operations and analyses of other aspects related to the issues above, including economical, technical, environmental and forestry aspects of forest biofuel production.[8]

2.1.1.1 Wood chips and sawmill residues

Wood chips for energy purposes can be produced from:

- top ends and other residues in the clear cuttings,
- the thinning of young tree plantations, or from
- trees which have been infected by rot, discoloration and fungus attacks, or that cannot be used as commercial timber due to other reasons.

The size on wood chips may vary between 5 and 50 millimetres. Sawmills generate a certain proportion of wood chips from the tree that cannot be used as timber, but sawmills also generates sawdust and shavings that can be used as raw material for production of pellets and briquettes.

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[6] Questionnaire, Lithuania, Research project #1
[7] Questionnaire, Latvia (Silvana), Research project #5
[8] Questionnaire, Latvia (Silvana), Research project #3

Logging is performed by using a feller (a special machine, which grabs the logs, cuts them close to the roots) or manually by using a chain saw. The chipping of the wood used for energy purposes can take place both directly in the forest or at the end user. The wood chips or logs are normally transported directly to energy plants but in some cases the logs/wood chips are stored in the forest, at the roadside or in the clearing.

What type of wood chips that is most suitable for energy proposes depends on the boiler that is used, but the most crucial criterion is generally the price of the wood chips. All plants want the cheapest fuel that their plant can handle. District heating plants tend to prefer coarse wood chips while power plants tend to prefer wood chips with varied particle size. The ash content in wood chips depends on the kind of wood, the quantity of needles, branches and steam wood as well as the amount of various pollutants (e.g. stones, soil and sand)[9]. The water content in the wood chips is another important factor, since it affects the heating value.

In Saare municipality, Estonia, a project for Bioenergy village development is being planned and partly implemented. The project takes place in the Kääpa village and one of the objectives is to buy wood chips produced locally from the forest owners nearby, owning the boiler house and selling the heat to the local inhabitants. Other objectives are to increase thinning activities and increasing the use of wooden by-products/production of man-made products.[10]

2.1.1.2 Wood logging residues

The logging residues include, for example, tops, branches, bark, and stumps. Removing logging residues from the forest may reduce the availability of essential nutrient minerals in the soil. Wood logging residues can be chipped in the forest directly or at the plant. Wood loging residues are rich in mineral nutrients and when wood residues are utilized, ashes generated from the combustion need to be recycled to the forest to prevent the loss of nutrients in the soil. Primarily, the logging residues are gathered and stored in log piles at the roadside, but an alternative is to store it in piles in the clearings for subsequent gathering when the needles have fallen off and the material is dryer. The moisture content is normally around 50 and 55 percent directly after harvesting but decline when logging residues are stored in the field or at the roadside.

[9] A high ash content can cause problems in the boiler.
[10] Questionnaire, Estonia, Demo site or pilot plant #1

In Lavijas Valsts Mezi (LVM) an upcoming domestic demand for forest residues was estimated to occur within a few years. To start the process of setting up an operation for extracting forest residues, LVM decided to carry out a research project. The project, which is now implemented, was focused on three main issues: (1) determination of extractable amounts of forest residues, (2) technology for extraction of residues and (3) costs for extraction. The research work was carried out by The Forest Research Institute of Sweden and LSFRI Silava. The work comprised of theoretical analyses as well as field work. The project ran from July 2005 to February 2006. The project has resulted in a production of about 200 000 of m^3 of forest fuel yearly by LVM, excluding firewood assortment.[11]

The Norwegian *project "Solid biofuels from Forest – Fuel specification and Quality Assurance" will focus on new wood substance such as branches, tree tops, and whole trees as well as properties important to new end products such as bioenergy and other products based on biomass. The project seeks to optimize the trading mechanism for forest biomass for bioenergy and other, new biomass based products.*[12]

2.1.2 Energy crops and agricultural residues

Biomass for energy purposes can be obtained from agricultural sector and the most significant sources are energy crops (e.g. reed canary grass, rape seed, short rotation forestry etc.) and agricultural residues (e.g. straw etc.). There is an on-going ethical debate focusing on the use of agricultural food products for energy or as raw materials for the production of renewable transportation fuels. This ethical debate includes the use of land for bioenergy production, which could be used for food production. A thorough discussion about this problem is beyond the scope of this report. At present, the agricultural areas in the Baltic Sea region are almost exclusively used for plant cultivation for food, animal feed, and provisions or for animal husbandry. Only a small part is used for energy purposes. The climatic conditions in different parts of the Baltic Sea Region affect the choice of crops grown.

In Germany Thüringer Landesanstalt für Landwirtschaft is leading a project called "Development and comparison of optimized cropping systems for agricultural production of energy crops under varying local conditions (EVA)". The project aims to evaluate and optimize different energy crop rotations according to their biomass and biogas potential under different local conditions. A few selected crop rotations were tested simultaneously on different locations across Germany. The results so far showed that highest yields can be produced with manifold cropping systems at all sites. In general, most successful crop rotation was maize, rye (green cut), sudan grass, triticale and rye grass. Highest yields were found for maize, but especially at sites suffering from drought sudan grass can be recommended as alternative. The winter grains showed also a high biomass potential at all sites and should be preferred at sites which are not suitable for maize production. Spring barley didn't achieve comparable high yields.[13]

Today, there are a number of production-related obstacles for energy crops. The production cost is relatively high for some of the agriculture crops and residues. Another, less expected obstacle is that energy crops may alter the landscape and this factor has led to public opposition against energy crop plantations in some regions.

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[11] Questionnaire, Latvia, research project #1
[12] Questionnaire, Norway, research project # 2
[13] Questionnaire, Germany, Research project #1

There is a resistance among farmers to go from annual crops to perennial crops, which change their work radically.

2.1.2.1 Fast growing energy forest (Willow)

Willow is a perennial agriculture crop that is cultivated for the production of willow chips for heat and power production. Willow may also be a potential raw material for the production of renewable transportation fuels through gasification. There are a large number of species of naturally growing willow, around 300 in all, but only a few have a growing pattern that is suitable for fast growing willow plantations, so-called energy forest. The life span of a willow plantation is estimated to be more than 25 years.

Willow has a high energy-in/energy-out ratio[14], large carbon mitigating potential and fast growth. Another unique property is that some varieties of willow are capable of taking up cadmium from arable land which means that willow can be used as a cleaner of the ground and thus reduce the risk of increased cadmium concentrations in foodstuffs (provisions); however, the cadmium rich fly ash from combustion of cadmium rich willow should not be recycled to the plantations.

Willow is best suited for clays and organic nutrient fields since it requires large amounts of water when it grows. Willow grows rapidly during the second year after planting. Plantation normally takes place from March until June and should, if possible, start as early in the spring as the weather and ground conditions permit. Early planting leads to better establishment and healthy growth during the first year. It is extremely important to control weeds during the establishment phase of willow, since weeds have a negative effect on the willow plants as they compete for light, water and nutrition.

Harvesting takes place in the winter (between November and April), when the growth has finished, the leaves have fallen, and the ground is frozen. Willow is harvested at intervals of 3-4 years and the yield can reach 7-10[15] oven dried tonnes of willow chips per hectare and year, although the first harvesting is normally smaller. Willow can be harvested, cut and chipped directly on the fields or as whole shoots.

Normally the willow chips are transported directly to heating plants after harvesting, primarily in bulk transport vehicles, but in some cases the chips are stored. Willow can be stored in chipped form in a stack or as whole shoots in a pile. There are a number of problems associated with the storage of willow chips in a stack. Freshly harvested chips stored in a stack break down faster, due to microbial activity. The advantage with the storage of whole shoots in a pile is that the moisture content is reduced from around 50 percent to approximately 35 percent between March and

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[14] The energy input in planting, maintaining and harvesting a plantation represent no more than 5 percent of the total energy value of the crop

[15] SOU (2007:36) Bioenergy from the agriculture – a growing resource, (Swedish)

September, corresponding to lower losses, higher density of energy, and better quality of the fuel.

Harvested willow chips are more or less equivalent to wood chips considering volume density and other fuel parameters. However, the size of willow chips is normally bigger, the share of fine particles is often lower, and the moisture content is usually higher. The moisture content is around 50 percent. When willow chips and wood chips are compared with each other, willow contains higher proportion of cadmium and zinc. However, wood chips contain higher proportion of copper. The quantity of metals has an important role concerning the handling of the rest product (ash).

The ash content varies between 1.5 and 3 percent of oven dried tonnes[16], but in the case when willow is stored outside as whole shoots, the ash content can be higher. The ash from willow contains relatively high contents of elements that lower the ash melting point, which means that problems with both sintering and coating may occur in the boilers (see chapter 2.3.1.2).

Willow chips are generally co-fired with wood chips and can be combusted in both grate boilers and in fluidized beds. The fraction of willow chips is usually between 5-15 percent; otherwise there is a risk for sintering and coating in the boiler.[17] However, practical experiences demonstrate that in some plants, the willow fraction has been nearly 100 percent without any significant problems in the boiler. In both circulating fluidized beds and bubbling fluidized beds, it is known that willow transfers itself up on top of the bed if the share of willow is too big. [18]

There is a great difference between the countries in the Baltic Sea Region regarding the production and use of energy crops like willow.

In Sweden, the R&D efforts have been intensive and well funded since the 1970s and as a result commercial plantations have been established. Lantmännen Agroenergi in Sweden works with planting and marketing of Short Rotation Coppice (SRC) Willow varieties, and the harvesting and marketing of SRC willow chips. Lantmännen Agroenergi are also the leaders in the field of crop breeding development of willow since they owns the part of Svalöf Weibull that develops willow. In Sweden, there are approximately 14 000 hectare of willow and Denmark has approximately 3000 hectare.[19 20]

[16] Lantmännen Agroenergi, site: www.agrobransle.se
[17] Forsberg M., et al. (2007), Agricultural supply of biomass fuels to large-scale Cogeneration plants – a case study of Värtan, JTI, (Swedish)
[18] Berg M., et al., (2007), Pre-study – compilation and synthesis of knowledge about energy crops from cultivation to energy production, Värmeforsk, (Swedish)
[19] Lantmännen Agroenergi, site:
[20] Ny Vraa Bioenergi, site: www.nyvraa.dk

In Latvia, SIA (Rīgas meži) has a 3 hectare demonstration field for different varieties of willows, including Swedish commercial clones and native species of willows. The demonstration field is used for production of planting material for commercial willow plantations and for dissemination within the scope of different research and development projects. The demonstration aims at initiating a discussion about willows as an energy crop.[21]

The Swedish University of Agricultural Sciences (SLU) lead a project called BIOPROS – Solution for the safe application of wastewater and sludge for high efficient biomass production in Short-Rotation-Plantation. The project finished in 2008 with participants from several countries, for example Estonia, Poland, Germany, and Finland. Since the economic situation for European farmers has deteriorated the last decade, there is an interest in finding new ways to adapt these businesses. Short-Rotation-Plantations (SRP) are considered a promising alternative source of income by cultivating fast growing tree-species as a source for bioenergy or different technical purposes under application of wastewater and sewage sludge for irrigation and fertilisation. Due to this procedure SRP are high efficient biomass production systems with additional contributions to a low-cost and environmentally safe biological wastewater and sludge treatment. The aim of the project was to gain knowledge about the economic, ecological and technical feasibility of SRPs for different local conditions. The main focus was on the safe and efficient application of wastewater and sludge to guarantee high yields and sufficient treatment performance without any negative environmental or hygienic impacts.[22]

2.1.2.2 Straw from various crops (e.g. wheat, rape)

Straw is a by-product from the growing of various crops (e.g. wheat, rape). After the 1973 oil crisis, straw was started to be used as fuel for heating production. Of the total production of straw, only a minor part is used for energy purposes. The major part is used in agriculture for soil amelioration by ploughing the straw back or by using it for feed, grain drying etc.

There are two common technologies used when harvesting straw for energy: rectangular bales and round bales. Shredding the straw in the field is an alternative harvesting method, e.g. when straw is used as a raw material for pellets or briquettes. However, the low density and relatively complicated handling make storage and long transport journeys expensive.

During storage, there are losses that are caused by microbial activity because the autumn climate can make it difficult to harvest the straw with sufficiently low moisture content. In both Sweden and Denmark, where straw-fired heating plants are common, a moisture content higher than 20 percent is usually not accepted.

Straw occurs in the form of powder, pellets, bales, or loose straw. Straw as fuel has a relatively high ash content, varying between 2.5 and 10 percent depending on the origin and technology by which it is burned. A problem with straw is that the ash starts to melt at a relatively low temperature, around 800-1000˚C, i.e. at a lower temperature than for most other types of biomass fuels. A low ash melting point leads to a higher risk of sintering in the boiler. [23]

[21] Questionnaire, Latvia (Silvana), Demo site or pilot plant #1
[22] Questionnaire, Estonia, research project #3
[23] Bernesson S. & Nilsson D. (2005), Straw as energy resource, SLU, (Swedish)

Straw used for fuel purposes usually contains 14-20 percent water. Straw has a high content of chloride and alkali metals that can cause problems like corrosion in superheaters or slag formation and blockages in different parts of the boilers. Therefore, straw which has been lying in the field after the harvest and that has become thoroughly wetted by rain (known as grey straw) is preferred, since the alkali levels in the straw thereby is reduced[24] Furthermore, the grey straw is easier to ignite. The same effect can be reached through straw washing at a temperature of 50-60 °C.[25]

Combustion of straw can be carried out in a vibrating grate boiler (see chapter 2.3.1.2) or in a combined powder and grate boiler. Due to the low ash melting point the temperature should not exceed 800-1000°C[26].

2.1.2.3 Grain and grain stalks

Grain can be classified as wheat, barley, or oats. Grain has traditionally been grown for food proposes, and there is a previously mentioned on-going ethical debate about using grain for energy purposes. The interest for using grain as fuel has been increasing in recent years, mainly on small farms. Grain can easily be fermented to produce ethanol.

There are relatively big differences in the quality of different types of grain as fuel. The quality of grain as fuel is affected by many factors, for instance, type of grain, the weather conditions during the year, and the cultivation measures. The ash melting point of grain is affected by both the elements contained in it and the mix of these elements.

2.1.2.4 Reed Canary Grass

Reed canary grass is a member of the Rhizome grass family. Common to all perennial Rhizome grass is that winter/spring harvesting is possible and gives a shrivelled and dry product under the conditions that dryness and/or frost causes the parts of the plant above ground to die off. Reed canary grass is of special interest in the northern part of the Baltic Sea Region since the crop can be grown on most soil types (however best on organic soil), and is not affected by the cold climate. Reed canary grass is used in agriculture for feed but a minor part is also used for energy purposes.

The seeds that are planted in year 1 are first harvested in the winter/spring of year 3 and then harvested at the same time year after year. Harvesting primarily takes place in the spring when a dry product is received with a water content of around 10-15 percent. The yield can reach 5-7 oven dried tonnes per hectare and year. The

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[24] Berg M., et al., (2007), Pre-study – compilation and synthesis of knowledge about energy crops from cultivation to energy production, Värmeforsk, (Swedish)
[25] Strömberg B., (2005), Handbook of fuels, Värmeforsk, (Swedish)
[26] Berg M., et al., (2007), Pre-study – compilation and synthesis of knowledge about energy crops from cultivation to energy production, Värmeforsk, (Swedish)

nutrients and elements that cause problems in the boiler have to a large extent leached out during the winter. Because of that, a small amount of nutrients are removed from the area during harvest.

A disadvantage with spring harvesting is that the period when harvest is feasible can be relatively short. This is partly because the ground has to be dry during harvest to minimize the risk for driving damage from harvesting vehicles, and partly because the harvesting must be done before new green shoots are established. The shoots can otherwise be damaged by the harvesting machinery, which will affect the next harvest yield in a negative way. Shoots may also contaminate the harvest, because of the high water content and the high amount of nutrients.

There are two common methods for seizing reed canary grass (for energy purposes) during harvesting and these methods result in rectangular bales and round bales. Shredding the grass in the field is an alternative harvesting method. Since reed canary grass has low water content (10-15 percent) there is a relatively small risk for microbial activity during storage.

Processed reed canary grass is found in the form of pellets, briquettes, powder, bales or as loose straw. Reed canary grass has a relatively high ash melting point in comparison with most other kinds of biomass. One of the main reasons for this is that some elements that cause a low ash melting point, e.g potassium have leached out during the winter. Reed canary grass contains a considerably higher amount of sulphur, nitrogen, and chlorine than wood fuel and wood pellets. This will lead to high emissions of nitric oxides and sulphur oxides when combusting reed canary grass.

When reed canary grass is used for energy purposes, the best combustions properties will be achived when the fuel is in the form of briquettes, pellets or powder; in addition these forms of reed canary grass makes it easy to handle.

2.1.2.5 Hemp

Hemp is an annual crop that must be planted annually. Hemp has extreme fibre strength in comparison with other straw fuels used in the Baltic Sea Region. The interest in hemp is not restricted to its use as an energy crop; its fibre can also be used for textiles, paper, insulation, and as strengthening in concrete, polymeric materials etc. The hemp seeds may also be pressed for oil, used directly in food products, or as animal feed.

Hemp for energy purposes is best harvested after the leaves have fallen off, which happens after the frost has set in. The nutrients in the leaves are not removed from the area during harvest and can benefit future crops. Frosts also cause the stems to dry and towards spring the steams become very dry (10 to 20 percent).Hemp that is harvested in the spring can normally be brought in with low water content.
There are two methods for seizing hemp (for energy purposes) during harvesting: in one method, the hemp is pressed into rectangular or round bales, in the other

method, loose material is chopped into small pieces. The hemps fibre can lead to problems during the harvest; the strong fibres can cause problems with screw feeds and other types of in-feed equipment where it is getting stuck and entangled.

Hemp intended for combustion is best without leaves, because the leaves contain high levels of potassium, sodium, and chlorine, elements that can cause problems in the boiler, e.g. sintering and build up with the risk of corrosion. The leaves also generate a great amount of ash. Hemp has two important disadvantages: it is far too dry to be fired as the only fuel in a boiler with a movable grate and that its volume is high, which lead to high storage and transport costs. To prevent this, hemp can be blended with other fuels, like wood chips.

The technology for refining hemp has not yet been fully developed in terms of fibre separation, grinding, conditioning, pelleting etc. Because hemp is an annual crop and frequently needs to be handled in bale forms it is expensive to produce hemp for large scale energy purposes. Hence, to grow hemp for energy as the sole purpose is not a realistic option.

2.1.2.6 Oil-seed crops

Oil-seed crops, e.g. rapeseed, soybean and sunflower can be converted into methyl esters. Rapeseed is one of the most widely grown energy crops in Europe. Rapeseed oil is produced by pressing the rapeseeds and then extracting the oil by steam and hexane. The by-product is a rapeseed cake, which can be used as a high protein animal feed. Rapeseed oil is used as raw material for producing RME (rape methyl ester) through esterification, see chapter 2.3.3.

2.2 Upgrading of fuels

Unrefined solid biomasses such as logging residues or reed canary grass are bulky and the quality can vary considerably. To get a more compact and manageable fuel, solid biomass can be upgraded to pellets, briquettes or powder. For those utilizing solid biomass there are many advantages in selecting an upgraded fuel, although it is more expensive; the demand for supervision is lower for upgraded fuels, the combustion process is more stable, and the storage volume will decrease as well as the costs for transportation. The combustion plant that is used can also be smaller and less expensive and will be operating during an extended part of the year. Upgrading of solid biomass can include one or several of the following stages; debarking, sieving, drying, pelleting, and mixing.

Drying solid biomass before it is upgraded requires safety measures to prevent problems with emissions or fire. A life cycle analysis study has shown that upgraded biomass, such as pellets and briquettes, has an effect on the environment that is in the same magnitude as using biomass that is not upgraded.[27]

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[27] Edholm A., (2000), LCA – analysis – A comparison based on one refined and one unrefined biomass fuel, Värmeforsk (Swedish)

2.2.1 Pellets and briquettes

Pellets

Production of upgraded fuels has increased substantially during the last few years and pellets is the most common of these. The preferred raw material for consumer pellets is sawdust and shavings, which are sawmill residues. The raw material basis for industrial pellets is wider and may include other sawmill residues, forest residues, or even roundwood. There is a great difference between the countries in the Baltic Sea Region regarding both the demand and the production capacities for biomass-derived pellets, see Figure 2.

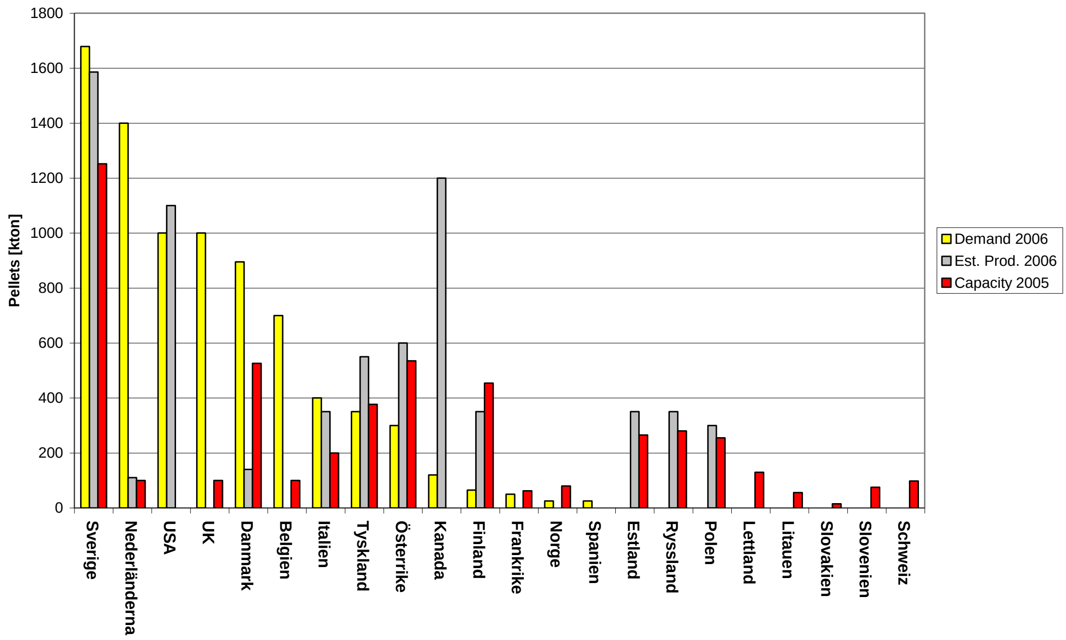

Figure 2. The demand and estimated production of pellets in year 2006. The figure also shows the production capacity for pellets in 2005. Source: Pelleta, IEA 2007

The large pellet producers have recently turned to buying roundwood, which is chipped and ground at the plant before being pelletized. This is mostly because there is a lack of the traditionally used raw materials. Pellets are produced by grinding the material before it is pressed in a plane or ring-shaped matrix pellet-press. Earlier the use of binding agents such as starch or lignosulphate was commonly added in order to increase the strength of the pellet. However there are indications that this may increase the ash content and the sulphur content, as well as cause problems in the grinding procedure. Therefore the use of binding agents is nowadays rare and it is common to only use water or steam during pelletizing.[28]

Wood pellets can both be used in industries and for private consumption. When produced for the consumer or household market, the pellets must satisfy certain requirements: a limited quantity of fines, ease of handling, minimum maintenance of

[28] Strömberg B., (2005), Handbook of fuels, Värmeforsk, (Swedish)

equipment, limited attention (e.g. removal of ash). These requirements have been translated into qualities defined in standards. The existing German, Austrian or Swedish standards for consumer pellets require that they are manufactured from sawdust or from sawdust and shavings without any bark.

From 2004 there is an EU norm CEN/TS 14961 that is being used more and more, and a European standard called CEN/TC 335 is under development. ERFO (European Recovered Fuel Organisation) is working on this standard. Except for requirements defined by the standards, there are other demands from the buyers, such as environmental concerns and sustainable production. Pellets are also ecolabelled and there is a Nordic brand called Nordic Ecolabel. For sustainable production there are FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification Schemes), which mean that the raw material is traceable so that the sustainability can be guaranteed.[29]

Means to increase the raw material basis for pellets are being considered in most countries. Relatively new categories of biomass materials that are used are short rotation crops (e.g. willow) and agricultural residues, such as straw. There are however problems in the combustion stage with pellets derived from these materials; they have a comparatively high ash content and will cause a low fusion temperature. Development remains to be done before these so-called mixed biomass pellets (MBP) will make an impact on the market. Even if the problems are overcome, the volumes available are rather small. Nonetheless, the problems with the high ash content are not limited to pellets derived from these new raw materials. Forest residues such as small branches and other discarded parts of harvested trees, usually have a larger proportion of bark than roundwood (stemwood). This implies a higher ash content in pellets from forest residues than those from sawdust or roundwood.[30]

The pellets factory in Köge, Denmark, is improving their method for producing straw pellets. Other projects have shown that a modification of the production machinery is needed to make pellets from reed canary grass, and the Canadian research project REAP (Resource Efficient Agricultural Production) has made pellets from switchgrass. [31]

Hallingdal Wood Pellets AS in Norway was established in the fall of 2004, and was the first in the world to produce pellets from raw material directly from the forest, ideally round logs. Hallingdal Wood Pellets gets its lumber from the forest: the trunks are splintered up, afterwards the raw chips are dried with warm air from the refuse disposal plant (Hallingdal Garbage Disposal), and some hours later these are manufactured into pellets. Hallingdal Wood Pellets was the only pellet producer in the world that uses low temperature drying in pellet production.[32]

[29] ÅF
[30] ÅF
[31] Berg M., et al., (2007), Pre-study – compilation and synthesis of knowledge about energy crops from cultivation to energy production, Värmeforsk, (Swedish)
[32] Questionnaire, Norway, Demo site or pilot plant # 7

The Swedish University of Agricultural Sciences (SLU) is hosting a national research program for fuel pellets together with the Swedish Energy Agency and the Swedish pellet industry association. The aim of the program is to produce more fuel pellet from a broadened feedstock, with a high productivity and performing higher product quality.[33]

Briquettes

Briquettes are larger than pellets and are mainly produced out of sawdust, cutter shavings and peat. Bark, wood chips, straw and reed canary grass can also be used. The briquettes normally have a diameter between 5 and 7.5 cm and a length between 1 and 20 cm.[34]

The production of briquettes can be divided into five steps: drying, comminuting, conditioning, densification and cooling. The need for drying depends on the material being used and the moisture content. About 8-12 percent is ideal for the densification. However, if there is a need for drying, it is possible that the raw material rather would be used for production of pellets, since the production of briquettes would be too expensive due to high drying costs.

Wood materials normally need to be chipped before they can be milled. After milling the material is sometimes softened by superheated steam before densification, which is a process that makes the material easier to handle. In the densification stage the material is being pressed to reduce the volume and there are a variety of techniques for this, for example, a piston press or different kinds of screw press technologies. After densification the briquettes are cooled to increase the strength. The cost for producing briquettes is lower than producing pellets since the cost for the machinery, such as mills and pressing machines, is lower.[35]

2.2.2 Powder production

Dry fuel can be upgraded to powder. Normally the deliverance of fuel to powder combustion plants is in form of pellets or briquettes which is grinded at the plant before combustion. Grinded powder is only delivered to boilers if the distance from the producer to the plant is small.

Since using powder as a fuel is more expensive than other forms of biomass raw materials its main application is when it is desirable to be flexible in fuels, for example, when co-firing biomass powder with oil or coal.

The first step in wood powder production is the separation of wood from unwanted waste. The wood is then coarsely grinded and dried until the moisture content is below 10 percent. After that, the wood powder is grinded again and the moisture content is even further decreased. There is a variety of grinding techniques. Hammer mills and beater mills are considered to give a good result. The particle size is usually below 1 mm and a part of the particles should be below 0.2 mm if the flame

[33] Questionnarie, Sweden Research project #2
[34] ÅF
[35] Strömberg B., (2005), Handbook of fuels, Värmeforsk, (Swedish)

is to be stable during combustion[36]. Since the powder is not compressed it is more bulky than pellets and briquettes.

The volume of wood powder is about ten times the volume of oil with the equivalent energy content; two tons of wood powder corresponds to one cubic meter of oil. A closed storage is needed for the powder, since it emits dust and the powder most be handled with care, because of the risk of explosions. Storage is possible for long periods and all year round.

2.2.3 Pyrolysis

Pyrolysis is a technology for upgrading biomass through thermal decomposition in the absence of oxygen. This is normally also the first stage in combustion and gasification, but these processes also include oxidation. The main reasons to upgrade biomass by pyrolysis are: to increase the energy density and thereby enable a more cost efficient transportation of the biomass and to facilitate feeding of the fuel to a gasifier or boiler.

There are a few different ways of performing the pyrolysis and these can results in a mixture of end products that differ greatly. If using a low temperature and a long vapour residence time, the fraction of charcoal in the end product will increase. A higher temperature in combination with a long residence time increases the gas production, giving up to 85 % gas. If the temperature is moderate and the vapour residence time is short, about one second, the end product will mainly be in liquid form. This is called fast pyrolysis; it is performed at about 500 °C and result in about 75 % liquid if using dry wood (the rest consists of charcoal and gas). Compared to other available techniques for upgrading biomass, the fast pyrolysis is still not that developed. However the technique is considered to be interesting, since liquid fuels offers advantages over solid biomass regarding, for example, storage and transportation.

Fast pyrolysis can be performed with more or less all types of biomass. A lot of different alternatives have been tested, but wood is the most commonly used. It is dried so that less than 10 % water remains and then it is grinded. A variety of reactors can be used for the pyrolysis. Bubbling fluid beds are considered having many advantages, since they are relatively simple to use, have a good temperature control and an efficient heat transfer. When using bubbling fluid beds the wood is grinded to a particle size of about 2 mm. The liquid is cooled after the pyrolysis. It is dark brown and has a heating value that is about half that of conventional fuel oil.[37]

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[36] ÅF
[37] IEA Bioenergy, (2007), Biomass Pyrolysis

In Finland, Metso and UPM-Kymmene Oyj is leading a project concerning Biomass-based bio-oil production. The project aims at developing a concept for the production of biomass-based bio-oil to replace fossil fuels in heating and power generation. Bio-oil can be manufactured by UPM's renewable energy power plants which are equipped with a suitable boiler and functional raw material management. Metso is in charge of the technological development of the pyrolysis reactor integrated into the boiler. The raw material of the bio-oil are harvesting residues and sawdust, which are by-products of the forest industry. The first ton of bio-oil was produced in Metso's pilot plant in Tampere June, 2009.[38]

In Norway, Xynergo AS will produce sustainable and competitive 2nd generation fuels for transportation and stationary applications utilizing low quality woody biomass. The company aims to build a bio-oil crude (Xyn-oil) plant in Follum, Norway that will be in operation by 2011 and a full scale synthetic diesel (Xyn-diesel) plant in operation by 2014. In the bio-oil crude plant they will use the pyrolysis process.[39]

2.2.4 Torrefaction

Torrefaction is a technique for upgrading biofuels where the volume is significantly reduced, while the reduction in energy content is relatively small. The driving force and interests for torrefaction are similar to pyrolysis, i.e. decreased costs of transportation of biomass and facilitated storage and feeding. Wood is heated in an oxygen free environment and the result is a product with 30 % less weight than dry wood while 90 % of the energy content in the wood is still left in the product (i.e. not considering the energy consumption of the torrecfaction process).[40]

The treatment is performed in temperatures ranging from 200 °C to 300 °C and at a pressure that is close to atmospheric pressure. The heating rate is low, less than 50 °C per minute. During the process volatile gases are released, reducing both the mass and energy content. Oxygen and hydrogen is lost to a larger extent than carbon. This is not only due to dehydration, but also through the loss of organic reaction products, such as, acetic acid, furans, and methanol as well as the gases carbon monoxide and carbon - and dioxide. The resulting torrefied biomass is brown colored and has properties that resemble the properties of coal.[41] Torrefacted wood do not absorb moist from the surrounding air and is therefore stable in comparison with pellets. This means that it can be stored in the open for long periods without major changes in its properties.

2.3 Conversion and use of fuel

Different forms of bioenergy are converted to other forms of energy through a variety of processes, such as solid fuel combustion, fermentation, biogas technology, thermal gasification, and esterification. The output from these conversion processes is in the form of thermal energy or upgraded biofuels and can be converted to the final energy use through various types of boilers and engines. The final energy use

[38] Questionnaire, Finland, Demo site or pilot plant #2
[39] Questionnaire, Norway, Pilot plant #3
[40] Freij J., (2009), Kolmilans renässans, Skogskrönika, Danske Bank (Swedish)
[41] Bergman, P. & Kiel, J., (2005), Torrefaction for biomass upgrading, Energy research Centre of the Netherlands

covers heating, electricity, and transportation (see Figure 1 in the beginning of chapter 2).

There is a wide variety of biofuels being used for vehicles, and a lot of research is going on to develop new alternatives. The total share of renewable fuels is however still small in most countries. FAME (Fatty acid methyl ester) and ethanol are the most common transportation fuels in the EU at the moment.

FAME is a generic term for biodiesels, and these are the bio-derived transportation fuels that are most commonly used in the European countries. They can be produced from a variety of renewable products. FAME can be mixed with regular diesel and according to an EU directive it is possible to add up to five percent FAME in regular diesel. However, FAME is sensitive to low temperatures, which means that a smaller proportion is used during the cold season in the northern European countries. Currently there is a discussion about expanding the limit in the EU directive to seven percent. Ethanol is also common in the EU. EU regulation makes it possible to add up to five percent ethanol in regular gasoline, but also here there is a discussion about expanding the limit to 10 percent. There are many ethanol vehicles available on the market today, most of them designed to use a mixture of 85 percent ethanol and 15 percent regular gasoline as well as pure gasoline.

Biogas is often considered to be the transportation fuel that has most environmental advantages. It can be mixed with natural gas and can therefore easily be used as a transportation fuel either on its own or in a mixture. Gas fuel vehicles also have the advantage of running quieter compared to conventional vehicles.

Vehicles can roughly be divided into light vehicles and heavy vehicles. DME (dimethyl ether) is considered a promising fuel for heavy vehicles in the future. It causes small amounts of emissions and the efficiency is high if taking the whole life cycle into perspective. However, the vehicles must be specially adjusted for DME, since the fuel must be held under high pressure to remain in liquid form. Another biofuel that is considered promising is methanol. It can be mixed with or substitute gasoline in a similar way as ethanol. Methanol can be produced through gasification of biomass and in Sweden massive expansion of methanol production is planed within the next few years. One of the planned factories in Hagfors in Sweden will be able to produce 120.000 cubic meters per year when it is finished in 2012.[42]

Conversion technologies for converting biomass into the above mentioned transportation fuels in the Baltic Sea region as well as combustion processes for biomass are described beneath. It is worth mentioning that not all technologies and processes are commercial today.

[42] NyTeknik, site: http://www.nyteknik.se/nyheter/energi_miljo/miljo/article674184.ece

2.3.1 Combustion for heat and electricity

To achieve optimal combustion of biomass, it is necessary for each process phase to take place under the right conditions. Important parameters are time, temperature and turbulence, which all must be fulfilled for optimal combustion. The combustion must continue for relatively long time, at appropriate high temperature and with sufficient turbulence. Other important factors affecting the combustion are the fuel´s ash content, ash composition, calorific value, moisture content, and size distribution.

Efficient combustion requires an optimal balance between the fuel and the combustion technology used. It is especially important to ensure that the oxygen content and amount of fuel are compatible for the process and boiler.

The Integrated European Network for Biomass Cofiring (NETBIOCOF) was a network consisting of participant from several European countries. The primary objective of NETBIOCOF Co-ordination Action was to promote European co-operation between research organisations devoted to biomass co-firing, promoting the uptake of innovative technologies to expand the use of biomass co-firing in new and existing power plants, with emphasis in the New Member States. A biomass co-ordination platform was established, which co-ordinated on-going research and strategic activities with the aim of identifying best practices and propose strategies of implementation and directions for futures research.[43]

Combustion technologies for small scale heat production and combined heat and power production are described beneath.

2.3.1.1 Small-scale heat production combustion technology

Small scale combustion refers to techniques for thermal systems smaller than 10 MW[44], for example, wood log or pellet stoves or boilers, open fireplaces and boilers for small district heating nets. Very small boilers are either manually or automatically fired. The biomass most commonly being used for small scale combustion are pellets, briquettes and wood powder.

Wood pellets are used for heating production on different levels, from small scale boilers to larger heating plants. Pellets are considered to be easily managed and the usage is steadily increasing. It is also easy to switch from oil to pellets in single family dwellings, since the same boiler may be used; however, slightly more supervision is needed and the burner and fuel handling system must be changed. Since pellets have a volume that is three times the volume of oil with the equivalent energy content, there is a need for extra storage space. 2.1-2.2 tons of pellets correspond to one cubic meter of oil. Pellets can be stored for long periods all year around, if they are kept in dry conditions.[45] Pellets with high ash content are not suitable in small scale boilers.

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[43] Questionnaire, Estonia, Research project # 2
[44] As a comparison it can be mentioned that a normal size of a single household boiler is 30 kW.
[45] Swedish Wood Fuel Association, site: http://www.tradbransle.se/pdf/faktablad_pellets.pdf

Briquettes are best suited for middle size plants with a power requirement of more than 400 kW. They can be burnt in a regular oil boiler and are therefore a good alternative if changing from oil to solid biomass. Special feeding equipment and an external combustor is required, and the volume of briquettes is three times that of oil with the equivalent energy content. Two ton of briquettes correspond to about 1 cubic meter of oil. Briquettes can be stored for a long time if the storing facility is dry.[46]

Small scale pellets and the briquette boilers above single family dwelling size will, if oil boilers are used, likely have the load slightly reduced and the need of flue gas treatment.

The Baltic Energy Conservation Agency S.A. has in the "Regional Bioenergy Initiatives around Europe (REGBIE)" project modernized a heating system in a public utility complex of buildings, encompassing elementary school and kindergarten. They have also modernized a local coal-fired boiler house, built a new pellets-fired heating system, and thermo-modernized these buildings. The duration time of the project was April 2004 to September 2004.[47]

The Regional office Czluchów in Poland has modernized the central heating system which included building a new heating system with straw-fired boiler and changing the system installation. Three objects were modernized: a school in Wierzchowo-Dworzec (400 kW boiler-house heats 2 buildings and the gym), a school in Barkowo (300 kW boiler-house heats 2 buildings and the gym), a school in Polnica (600 kW boiler-house heats 2 buildings, the gym and the health centre). The duration time of the project was 2003-2004. [48]

2.3.1.2 Combined heat and power production combustion technology

There are some different types of boilers that can be used for heat and/or power production. Grate boiler, fluidized bed boiler, and powder boiler are described in the following sections. Gas turbines are described in chapter 2.3.2. When using biomass as fuel it is more common to use a fluidized bed when the effect is 30 MW or higher[49], since the fluidized beds are more cost effective in large boilers. In addition, the fluidized beds also have better environmental performance than grate boilers. When the effect is lower than 30 MW it is more common to use a grate boiler, since a fluidized bed is less cost effective in small boilers.

The Vilnius District Heating Company, Lithuania are reconstructing steam boilers for adjustment to use biomass. One steam boiler was reconstructed in 2006. The capacity of the biomass fired boiler is 75 MWth. For two more (present capacity 70 MWth and 540 MWth (12 burner each with 45 MW)) the feasibility study for reconstruction is under preparation. Another example from Lithuania is the district heating company in Utena , who has installed a biomass boiler (8 MW) in year 2002, They are also planning to install a biomass CHP plant with 2,1 MWe and 8,6 MWth.[50]

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[46] Swedish Wood Fuel Association, site: http://www.tradbransle.se/pdf/faktablad_briketter.pdf
[47] Questionnaire, Poland, Demo site #2
[48] Questionnaire, Poland, Demo site #9
[49] ÅF
[50] ÅF

Grate Boiler

In a grate boiler the fuel is spread out on a grate where it is combusted. There is a variety of designs being used. For example air can be blown from the side and/or from underneath, and the grid can have different designs. The simplest model consists of a plane grate located at the bottom of the boiler. These are normally being used in very small plants. A sloping grid is more commonly used in larger boilers. The bars of the grid can be either fixed or movable in relation to each other due to a hydraulic system that influences the feeding of the fuel. The fuel is added from above and combusted as it slides down the grid. This is especially suitable for fuels with high moisture content. On the grate, the fuel is dried, pyrolysed and finally burnt.

When operating a grate boiler the management and feeding of fuel to the boiler is the procedure that needs to be given the most attention. It is important that the fuel is evenly spread out on the grid; some parts might be left unburned if the layer is too thick. To get even spreading, automatic equipment, so called stokers, can be used. There are a few different designs for these. For example, screws, ram stokers and spreader stokers that spreads the fuel over the grid.

Fluidized bed

In a fluidized bed the combustion does not take place on a grate. Instead, the fuel floats in a combustion compartment that consists of a hot bed of sand. This state is created by generating a strong air stream through the bed of sand which keeps the fuel in a floating position. A fluidized bed facilitates the combustion of a variety of fuels, even fuels that can be difficult to burn in a regular boiler. The technique has been used for a long time in the chemical industry, and due to increasing environmental demands as well as increasing oil prices this technique is being used more and more for combustion of solid fuels. Since the combustion temperature is relatively low, the emissions of thermally generated nitrous oxides from bio-fuelled fluidized beds can be kept low, which is also the case for most other types of bio-fuelled boilers.

There are two main groups of fluidized beds; Circulating Fluidized Bed (CFB) and Bubbling Fluidized Bed (BFB). The main difference is the gas velocity. In BFB the velocity is between 0.5-3 m/s and in CFB between 2-8 m/s. CFB was initially developed for burning coal in larger plants, and it is considered to have a higher flexibility for different fuels as well as being more swiftly controlled. [51]

The bed in a BFB boiler consists of ash- and sand particles that float in the lower part of the boiler due to an air stream from below. The fuel is added, as well as additives (such as limestone and dolomite) for flue gas cleaning. The bed material is preheated with a gas or oil burner until it reaches the auto-ignition temperature of the fuel. Air is added from below through blowing fans. When the boiler is heated, the solid fuel that is added will combust spontaneously. Since the fluidization

[51] Eriksson, L. & Ingman, R., (2001), Recommendations for conversions of grate fired boilers to fluidising beds, Värmeforsk (Swedish)

velocity is low in BFB, there is a distinct difference between the lower and upper part. Air is added in the free board above the bed, and because of that the temperature in this part of the boiler can be as much as 200-250 °C higher than in the actual bed.[52]

The CFB is based on the same technique as a BFB, but with a higher fluidization velocity. Because of this a part of the bed material follows the gas up through the boiler. It is separated in a cyclone and brought back to the bed. The content of the boiler is therefore relatively homogeneous, but with a density that decreases with the elevation.

There is an important difference between a grate boiler and a fluidized bed boiler. The temperature in the combustion chamber in a grate boiler is approximately 1100°C in the vicinity of the grate and may locally also be higher. In a fluidized bed boiler, the temperature in the bed is relatively constant at 750-950°C. The lower temperature is possible due to internal heat exchange surfaces and flue gas circulation. [53]

Powder boiler

A powder boiler can be used for different kinds of pulverized fuels. Powder burners can often be multifuel burners that are capable of burning other fuels in gas or liquid form. A fire grate is thereby not needed and it is therefore common that powder burners are installed in old oil boilers to convert the boilers from heating oil to biomass. Another application is when a new biomass-based combined heat and power plant is being built with not enough room for a fluidized bed or grate boiler. However, one important drawback with biomass powder boilers is that fouling might occur.[54]

Powder is so far mainly used in boilers with an effect of about 1 MW or more. This is mainly due to the fact that there is a lack of equipment for smaller boilers. There are in theory no problems with smaller boilers for wood powder. A silo or similar closed container is needed for storage and the volume of wood powder is ten times that of oil with the equivalent energy content. Two ton of powder corresponds to about 1 cubic meter of oil.

The powder is blown into the burner using air or chimney gases. Smaller powder combustion plants usually use pellets that are grinded before being feed into the burner. The powder is ignited by a gas or oil burner. Oil can also be added at low load to facilitate the regulation and thereby giving a more stable operation. This is called support combustion. The combustion of powder is relatively easy to control and so are the pollutants in the flue gases.[55]

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[52] Berg, M., et al., (2003), Combustion of waste wood – second phase of the collaboration project on waste wood combustion, Värmeforsk (Swedish)

[53] Berg M., et al., (2007), Pre-study – compilation and synthesis of knowledge about energy crops from cultivation to energy production, Värmeforsk, (Swedish)

[54] Swedish Wood Fuel Association, site: http://www.tradbransle.se/pdf/faktablad_trapulver.pdf

[55] Swedish Wood Fuel Association, site: http://www.tradbransle.se/pdf/faktablad_trapulver.pdf

Denmark use about 1.5 million tons of straw per year.[56] About ten percent of this is used in the Avedøre 2, outside of Copenhagen. Avedøre 2 is a combined heat and power plant and it is the world's largest of its kind. It consists of three parts. The main boiler is a burner that can be fired by gas, oil or bio powder. Beside that there are gas turbines being used at peak load and a straw boiler that generates process steam. The plant has a maximum electric output of 535 MW and a maximum thermal output 620 MW.[57] It has been in operation since 2001 and is the main heat source for Copenhagen district heating system, which is one of the largest district heating systems in Northern Europe. The plant can also handle other types of biofuel, for example pellets, as well as fossil fuels. However, in Avedøre 2 each type of fuel is burnt in a separate sub-system so that the conditions for each fuel can be optimized. The straw boiler has a capacity of 105 MW steam at 310 bars pressure, with a steam temperature of 583 °C. It is the world´s most effective straw fired boiler.[58] The electrical efficiency of the plant is 49 % and the total efficiency 93.2 %.[59]

Combustion related problems

Biomass has a number of properties that involve huge challenges when they are used for the production of heat and electricity. Biomass is much more bulky than coal and oil, so the heat and power plants have to handle much larger quantities of fuel. Biomass also contains alkali metals and chlorine, which may cause problems linked to sintering and corrosion.

Problems related to superheater corrosion limit the pressure in a boiler as well as the steam temperature, and the steam in the outlet can therefore not exceed 600 °C[60] in modern boilers. This limits the thermal efficiency. The main reason for high temperature corrosion in boilers using solid biomass as fuel is chlorine and potassium. Some corrosion is normal in all boilers though a layer of oxides generally develops and this oxide layer protects the metallic surfaces to a certain level.

Sintering is a phenomenon which causes problems when firing biomass in fluidized beds. Sintering means that low melting inorganic compounds (i.e. ash) melts or become "sticky" in the bed. This means that larger agglomerates are formed in the fluidized bed due to merging of particles in the bed caused by the sticky nature of some particles. This may cause the fluidized bed to stop fluidize with the result that the operation must be shut down. Therefore, it is crucial to operate a fluidized bed well below the ash melting point of the biomass fuel in order to avoid sintering problems.

2.3.2 Biogas production based on digestion

Biogas consists of 45-85 percent methane and 15-45 percent carbon dioxide. The proportion depends on the conditions during production (temperature, substrate, digestion technique, pre-treatment, etc.). The gas also contains small amounts of hydrogen sulphide, ammonia and nitrogen. Biogas can be used for local heating, to generate electricity, and also as a transportation fuel.

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[56] World Bioenergy, site: www.elmia.se/sv/WorldBioenergy
[57] Babcock & Wilcox Vølund A/S, (2008), Avedøreværket Plant fact sheet
[58] Ottosen, P., (2005), Avedøre unit 2 - the world's largest biomass-fuelled CHP plant, DBDH
[59] Babcock & Wilcox Vølund A/S, (2008), Avedøreværket Plant fact sheet
[60] Berg et al. (2003), Combustion of Waste wood – Second phase of the collaboration project on waste wood combustion, Värmeforsk (Swedish)

Biogas is produced when organic material is decomposed by microorganisms in an anaerobic (oxygen-free) environment. This process is performed in a biogas plant, where organic material is pumped or placed into a digestion reactor (digester). There are several categories of useful raw materials (substrates) from which biogas can be produced in a digester, for example, sludge from sewage treatment plant, manure, agricultural crops, food waste from households, etc. The substrates vary relatively much with regard to dry substance and the possible yield of methane. The most common substrate in, for example, Sweden and Poland is sludge from municipal sewage treatment plant, which has low dry substance, small particle fraction and does not need any pre-treatment before digestion. Many substrates can be digested simultaneously in a biogas process, so called co-digestion. Compared with the digester of sludge from sewage treatment plants, co-digestion with a variety of substrates usually results in higher methane content (yield) in the biogas.

The BIOTILA project in Finland aims at developing biogas technology from agricultural resources. The project hope to create examplatory biogas concepts based on the regional agricultural features of eastern Finland which is the main milk production area in Finland. The concepts range from farm-scale plants with farmbased raw materials to larger centralised plants with wider raw material use. Technological applications, economic profitability, environmental balances and life cycles of the concepts will be determined. The first pilot farm scale biogas plant has been opened in Maaninka in the spring 2009.[61]

BioWas AS is a Norwegian private company with joint research collaboration with the Norwegian University of Life Sciences and the Norwegian Institute for Agricultural and Environmental Research (Bioforsk). They develop and sell farm based biogas systems. Their new patent consists of standardised, module-based components which makes the investment cost substantially lower than existing known products on the market. A prototype of the basic Biowaz reactor was built in the autumn of 2006 and a full scale pilot plant is now in operation and several other test plants are being built or projected. In 2009, three BioWaz plants are sold in Norway and one in Sweden, and they expect to sell between 5-10 plants in Norway and Sweden during 2010.[62]

In February 2009, a project in Finland named "Processing biogas plant digestates into value-added products" started. The aim of the project is to develop technologies and practices which can use different organic by-products and waste materials for biogas productions, and which can be used for production of competitive and safe products for various end uses. Many different raw materials with different characteristics are studied. The products are prepared on-site as well as in pilot and laboratory scale studies by using different physical, chemical and biological unit processes. [63]

The biogas process can be divided in four different general steps: hydrolysis, fermentation, anaerobic oxidation and methane formation, as can be seen in Figure 3.

[61] Questionnaire, Finland, Demo site or pilot plant #3
[62] Questionnaire, Norway, Pilot plant # 1
[63] Questionnaire, Finland, Research project # 1

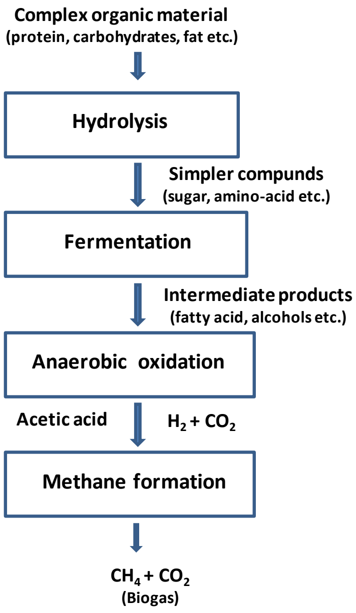

Figure 3. The biogas process can be divided in different steps

Usually, the substrate must be pre-treated, which includes decomposition (to increase its availability to the microorganisms), stratification, conditioning and sanitation before it can be added to the process. If materials of animal origin (e.g. slaughterhouse waste and manure) are used as substrate it is common that these substrates must be pasteurized (at about 70˚C in 1 hour) before they can be digested (due to the risk of infection). The next step is hydrolysis, where the microorganisms (in the presence of enzymes) decompose complex organic compounds to simpler compounds, for example, amino acids, and sugar. During the fermentation, a number of intermediate products are formed, such as, fatty acid and alcohols. Before the formation of methane, anaerobic oxidation occurs in the process where acetic acid, hydrogen gas, and carbon dioxide are produced. In the last step, methane gas is formed by a unique group of microorganisms, so-called methanogenes. These microorganisms grow slowly and cannot live in the presence of oxygen.

The process is very sensitive for contaminations and important factors to consider in anaerobic digestion are, for example, supply of water and nutrition, temperature, and pH. Two different temperatures are generally used in the process, 37 ºC (so-called mesophilic) and 55ºC (so-called thermophilic).[64] A thermophilic process gives a faster digestion than a mesophilic process as well as a higher gas yield. However, a thermophilic process requires much more energy for heating. The retention time in the digester varies depending on the properties of the substrate and on the extraction rate of methane. Substrates from sewage treatment plants usually need the shortest retention time, whereas co-digesters often require longer retention times. The retention time usually varies between 16 and 30 days.

[64] Swedish Gas Association

In the Polish project "Agricultural Biogas Plant" two biogas plants have been built by Polandor S.A. The raw material being used in the plants are for example liquid manure, corn silage, and biomass waste. The plants will generate 2 300 000 m^3 respective 7 800 000 m^3 biogas annually. The plants also include electrical and power heat modules and gas fired boilers which will generate heat and electricity.[65]

At most biogas plants there are boilers/burners where the biogas often is used to heat nearby buildings. However, if there is a demand for biogas as a transportation fuel it is normally more profitable to upgrade the biogas as transportation fuel and use district heating to heat nearby buildings instead. At present, there are problems to store and transport biogas at a low cost, which may lead to flaring when the supply of gas is larger than the demand of heat. This is especially common during the summer. The biogas can be distributed in separate pipes or through the existing gas grid (however, the gas need to be upgraded to attain the same properties as natural gas). Biogas can also be transported as compressed gas or in liquid form. There are intensive research and development going on for new systems for storage and distribution of biogas, which is relevant in areas where there are no infrastructures for natural gas.

When only heat is produced, the gas must be dried before combustion. Biogas can be used to produce both power and heat in gas turbines or gas burners. About 30-40 percent of the energy can be extracted as electricity and the remainder as heat.[66] So called combined cycles are common where a gas turbine is combined with a steam turbine. The hot flue gases from the gas turbine are lead to a boiler that generates steam for the steam turbine. This increases the electrical as well as the total efficiency of the system.

The DH company Kauno energija in Lithuania invested in the construction of the new CHP plant in Noreikiškės, operating on biogas from Kaunas waste water treatment plant. Noreikiškės CHP plant is the first among Lithuanian district heating companies to operate such type of power plant using biogas. The water treatment plant produces 1.8 million m^3 of biogas annually and uses it for plant heating needs. Approximately 50% of excess gas was transferred to the CHP plant instead of emitting it to the atmosphere. The main energy equipment of the CHP plant is 150SP BIO engines (5 units). Installed capacity of the plant is 0.75 MWel and 1.05 MWth. The biogas is diluted with small amounts (up to 30%) of natural gas. The installations of the power plant are connected to the 0.4 kV bus and to the grid of West Distribution Grid company by 10/0.4 kV transformer. Heat produced at power plant is supplied to academic settlement of Noreikškės.[67]

The Lithuanian energy company Ekoresursai has installed a biogas collecting system and a biogas CHP plant in Kaunas landfill Lapes, which is operated by the waste management company Kauno Švara. The CHP has an electric capacity of 1.1 MW and a thermal capacity of 1.4 MW. Produced electricity is supplied into the national power grid. Currently the company is implementing a similar project at a landfill in Šiauliai region.[68]

[65] Questionnaire, Poland, Demosite # 7 and Demosite #8
[66] Swedish Gas Association
[67] Questionnaire, Lithuania, Demo site or pilot plant #2
[68] Questionnaire, Lithuania, Demo site or pilot plant #1

In Latvia, Dobeles region, a project is carried out called "Biogas production and cogeneration plant in Agriculture Training and Research Farm". A biogas production and cogeneration plant was commissioned in October 2008. The plant heat energy output is 356 kW and power output is 280 kW. The efficiency of the heat production is 0.45, power production 0.35 and summary efficiency of the plant is around 0.81. The raw material for biogas production is cows' manure, from a dairy farm situated nearby, mixed with maize and grass silage. The cow's slurry is collected in a storage tank (4000 m^3) and then pumped into a fermenter (2000 m^3). Hydraulic retention time of mixture is up to 20 days at temperature 38°C.[69]

The village Jühnde is the first place in Germany, which completely covers the energy needs from renewable energy sources. This successful concept is inspiring example for a number of bioenergy villages, assistance measures and competitions. Within the project, focusing on both electrical power and heat, a CHP-unit was built and runs by biogas. For additional heating during winter a wood hogged heating system was established, which can be run either with wood chips or straw. The power supply is more than double than required, about 5 GWh annually, and the heating supply covers three fourths of the requirement. The waste heat is used for drying (wood chips, grain).[70]

In Poland a demonstration bio-gas power plant in Pawłówko was built in 2005. The biogas plant consist of a raw material reception station, primary tank with pumping station, two digestion tanks, technical facility with hygienisation unit and a post-digestion tank. The annual input is about 29000 tons liquid manure, 5500 tons maize silage, 3000 tons slaughter waste and 1000 tons glycerine. The total capacity of the digestion chambers is 1500 m^3. There are two combined heat and power stations with the electric power of 230kW and 495 kW and a gas boiler with the thermal power of 350 kW. The total annual production is approximately 1500000 m^3 of biogas, 3000000 kWh electric power and 3900000 kWh thermal energy. [71]

The use of biogas as a transportation fuel is gradually growing. In Sweden the number of filling stations increases with about 20 percent annually[72]. When biogas is used as transportation fuel, the gas must be upgraded which means that the energy content must be increased by the removal of carbon dioxide together with water and contaminants, such as hydrogen sulphide. Furthermore, the gas must be compressed to a pressure of about 200 bars before it can be used.[73]

The remainder after the digestion forms a digestion residue with high water content that contains organic material, microorganisms and various nutrients. The nutrient-rich residue can be used as fertilizer and is a good soil conditioner. If the residue is supposed to be used as a fertilizer, it cannot contain contaminants like heavy metals, traces of medical drugs, etc. Because of the high water content, the digestion residues cannot be transport too far from the plant, which can cause a surplus on the nearby market. When the biogas is produced by substrates like relatively uncontaminated organic wastes, such as, manure, source-sorted food wastes, crop residues, process water from the food industry, etc., the residue is usually termed bio-manure.

[69] Questionnaire, Latvia (LLU), Demo site or pilot plant #1
[70] Questionnaire, Germany, Demo site or pilot plant #1
[71] Questionnaire, Poland, Research project #4
[72] Gasföreningen, site: http://www.gasforeningen.se/upload/files/faktaomgas/fordonsgas/fordonsgasfakta%20uppdaterad%20sep%202008.pdf
[73] Swedish Gas Association

There is a big difference between the countries in the Baltic Sea Region in how far they have reached in the development of biogas technology. Table 4 shows the development of biogas in each country in the region.

Table 4. Development of produced biogas[74] for the countries in the Baltic Sea region [GWh]. Sources: IEA, Eurostat

	1991	1993	1995	1997	1999	2001	2003	2005	2007
Belarus	0	0	0	0	0	0	0	0	N/A
Denmark	256	302	488	663	733	849	989	1058	1087
Estonia	0	0	24	16	30	23	31	41	49
Finland	0	0	0	140	209	198	233	488	427
Germany	3396	3884	3873	4547	4222	9792	10676	15480	27715
Latvia	0	0	0	0	0	0	45	94	87
Lithuania	0	0	0	0	0	0	22	21	28
Norway	58	N/A	186	291	302	267	302	291	N/A
Poland	58	12	151	186	291	407	454	628	728
Sweden	0	244	291	512	337	395	419	349	1054

Table 5 provides information about the proportion of the primary production of biogas in percent and the gross electricity production from biogas in the region in year 2007.

Table 5. Primary production of biogas and gross electricity production from biogas in the Baltic Sea Region in 2007. Source: EurObserv´ÉR

Country	Landfill gas [%]	Sewage sludge gas[1)] [%]	Other biogas[2)] [%]	Gross electricity production from biogas [GWh]
Belarus	N/A	N/A	N/A	N/A
Denmark	11	22	67	271
Estonia	73	27	N/A	14
Finland	72	28	N/A	22
Germany	18	11	71	9520
Latvia	71	29	0	37
Lithuania	68	32	N/A	6
Norway	N/A	N/A	N/A	N/A
Poland	30	69	1	160
Sweden	21	58	21	36

1) Urban and industrial
2) Decentralised agricultural plants, municipal solid waste methanisation plants, centralized CHP

2.3.3 FAME (Fatty acid methyl ester) production through esterification

FAME (a generic term for biodiesel) generally refers to methyl ester made by transesterification in the presence of a catalyst. Transesterification is a chemical process where a triglyceride reacts with an alcohol (usually methanol).There are several categories of useful raw material from which FAME can be produced, for

[74] For the IEA data it is stated that "[i]ncluded in this category are landfill gas, sludge gas and other biogas such as biogas produced from the anaerobic fermentation of animal slurries and of wastes in abattoirs, breweries and other agro-food industries."

example, vegetable oil (e.g oil derived from rapeseed, sunflower, soy, etc.), animal fat (pork lard, beef tallow, etc.), or used frying oil.

FAME can be produced by a variety of esterification technologies, but most processes follow a similar basic approach. The general biodiesel process can be divided into a number of steps. The first step is when the oil is filtered and pre-processed to remove water and contaminants. If there are any free fatty acids present, they can be removed, esterified into biodiesel, or esterified into bound glycerides. The oil is then mixed with an alcohol (commonly methanol) and a catalyst (usually sodium or potassium hydroxide). In this step, a sufficient amount of alcohol is added to reach equilibrium; generally six parts of methanol to one part of triglyceride is added to drive the reaction to completion. The triglyceride molecules are broken apart and reformed into FAME and glycerol, which are separated from each other and purified. Since the density of glycerol is higher than that of biodiesel it is easy to separate the products from each other. Residual methanol is typically removed through distillation and reused.[75] [76]

The by-product glycerol can improve the economics of making biodiesel if there is a demand on the market. Glycerol is a chemical that can be used in the cosmetic and the pharmaceutical industries; however, the market for its use is limited.[77] Table 6 shows the development of produced biodiesel for the countries in the Baltic Sea region.

Table 6. Development of produced biodiesel[78] for the countries in the Baltic Sea region [GWh]. c=confidential. Source: IEA

	1993	1995	1997	1999	2001	2003	2005
Belarus	0	0	0	0	0	0	0
Denmark	0	0	0	0	256	465	744
Estonia	0	0	0	0	0	0	0
Finland	0	0	0	0	0	0	0
Germany	47	361	930	1349	3617	8269	20713
Latvia	0	0	0	0	0	0	26
Lithuania	0	0	0	0	0	0	93
Norway	0	0	0	0	0	0	c
Poland	0	0	0	0	0	0	651
Sweden	0	0	0	0	23	35	70

[75] Gode et al., (2008), Efficient production of biofuels for transport, Swedish District Heating Association, (Swedish)
[76] Biofuels for transport – An International Perspective, IEA
[77] Biofuels for transport – An International Perspective, IEA
[78] IEA states that ” Biodiesels includes biodiesel (a methyl-ester produced from vegetable or animal oil, of diesel quality), biodimethylether (dimethylether produced from biomass), Fischer Tropsh (Fischer Tropsh produced from biomass), cold pressed bio-oil (oil produced from oil seed through mechanical processing only) and all other liquid biofuels which are added to, blended with or used straight as transport diesel. Biodiesels includes the amounts that are blended into the diesel - it does not include the total volume of diesel into which the biodiesel is blended.”

Perstorp BioProducts in Sweden produce RME and the major part is sold to oil companies who blend 5 % of RME in fossil diesel. Perstorp BioProducts also has developed a renewable fuel called Verdis Polaris. Verdis means that the climate benefit is high since it is renewable. Polaris signifies its remarkable quality as it can be used in the far north of Sweden on the coldest day.[79]

The Norwegian project Uniol AS will offer biodiesel produced in Norway with a high environmental security and high quality. Uniol has invested in multifeed technology to ensure large feedstock flexibility and their primarily feedstock are rapeseed, soybeans and tallow. They expect that the plant will be in full operation by the end of 2009 and the biodiesel produced is already located in the Norwegian market. By the end of 2009, they will export biodiesel to Poland. [80]

In Finland, Neste Oil has a vision to be a world class operator in biodiesel. They have developed hydrogenation technology so they can use all kinds of oxygen rich bio-oil as a feed material in their fossil oil refineries.[81]

2.3.4 Ethanol production technology based on fermentation

Ethanol (ethyl alcohol) produced by fermentation can be carried out with different kinds of biomass containing sufficient amounts of starch or sugar. There are several categories of useful raw materials from which ethanol currently are being produced, for example, cellulose based raw materials (forest residues, energy crops, wastes from pulp and paper processes, etc.), starch crops (cereal grains, corn, etc.) and sugar crops (sugarcane, sugar beets, etc.). At present, fermentation of starch crops and sugar crops are commercial on the market. On the other hand, there is presently no direct commercial production of ethanol from cellulosic biomass, but in countries like USA, Canada and Sweden, there are a lot of research efforts put into this area. There are several potential benefits with the cellulosic ethanol process, for instance, access to a much wider group of potential feedstock and less risk for conflicts with land use for food and feed production. The fermentation process for ethanol can be divided in three steps: pre-treatment, fermentation, and upgrading. The key steps are shown in Figure 4

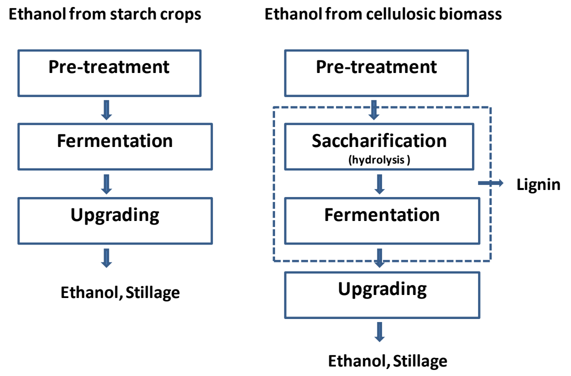

Figure 4. The key steps for ethanol production from starch crops and cellulosic biomass.

[79] Perstorp BioProducts, site: www.perstorpbioproducts.com
[80] Questionnaire, Norway, Pilot plant #2
[81] Neste Oil

The first step, pre-treatment, includes separation, cleaning and milling of the feedstock. Milling can be either wet or dry. In both cases, the starch is converted to sugar by using high temperature and enzymes. The next step is fermentation where the sugar is fermented to alcohol by using yeast or other microbes. In the final step, upgrading, the ethanol is distilled to the desired concentration and the water is removed.

Lantmännen Agroetanol is the only full-scale producer and supplier of cereal based fuel ethanol in Sweden. The plant is also one of Sweden's largest producers of protein feed stuff. The plant has a favourable energy balance since renewable energy is used in processing at the plant. The ethanol being produced is mainly used for low blending in regular petrol. The plant is operated continuously and has a production capacity of 210,000 m^3 ethanol per year. [82]

There is a difference using cellulose as a raw material compared to starch crops. When ethanol is produced from cellulose and hemicelluloses, the feedstock first has to be converted into sugar through a process called saccharification before it can be converted to alcohol. A combination of chemical and physical processes is common as a pre-treatment step before the saccharification step. This allows separation of the feedstock into its cellulose, hemicelluloses and lignin components; some hemicelluloses can be converted to sugar and some of the lignin is removed. In the saccharification step, the remaining cellulose is hydrolysed into sugars. Common methods are dilute acid hydrolysis or processes where enzymes break down cellulose and hemicelluloses. There are two different types of enzymatic hydrolysis: separate hydrolysis and fermentation (SHF) or simultaneous saccharification and fermentation (SSF).

The remainder of the ethanol process is called stillage and when ethanol is produced from starch crops the stillage can be used as raw material for animal feed. When ethanol is produced from lignocelluloses material the remainder also contains lignin, which cannot be converted to sugar. However, ,the stillage can be used as fuel for heat and power production, as a raw material for pellet production, or it can be converted to liquid fuel through gasification and gas- to liquids conversion, see section 2.3.5.

The Norwegian Forest and Landscape Institute together with the University of Minnesota, carry out a project to develop new ways of extracting and utilizing the vast quantities of cellulosic sugars (cellulose) found in plants to produce ethanol. However, the starting plant materials also contain lignin which effectively blocks the economical degradation of cellulose to simple sugars. Some fungi are able to degrade lignin, and the project aims at identifying the genes that fungi naturally activate as they transition from growth on simple sugars to growth on wood, since these genes are most likely involved in lignin degradation. [83]

[82] Questionnaire, Sweden, Demo site or pilot plant #2
[83] Questionnaire, Norway, Research project #3

SEKAB in Sweden have been involved in the cellulosic ethanol development since the end of 1980s and have an ethanol pilot plant that was opened in 2004. The plant is designed to produce the necessary expertise for the expansion to commercial production. The development process includes everything from raw materials, chemical and biological processes, management and process control technology to integration with other kinds of production. The current raw material used is wood chips from pine trees but other raw materials such as energy grass and recycled waste are also of future interest for the project.[84]

2.3.5 Transportation fuel production based on thermal processes

Biomass gasification is a process used to convert solid fuels to syngas, mainly consisting of carbon monoxide (CO), hydrogen (H_2) together with traces of methane (CH_4), carbon dioxide (CO_2), and water (H_2O). The syngas can be used in a variety of ways to produce a final transportation fuel (e.g. FT-diesel, DME, methanol, synthetic natural gas, etc.) or it can be burnt for heat and power production in a gas turbine or gas burner. DME, which is a gaseous fuel, is not yet compatible with today's gasoline or diesel vehicles but there is substantial research going on in this area.

There is a variety of processes available for biomass gasification and also for converting syngas into a final transportation fuel. However, in general the processes for production of Fischer-Tropsch diesel, methanol, DME (dimethyl eter), hydrogen and bio-methane (synthetic natural gas, SNG) are in many respects relatively similar, but differ after the production of the syngas, see Figure 5. The biomass used in gasification needs to be relatively dry (10-15 percent water content). When biomass has been used as the raw material for the production of liquid biofuels, the process is called BTL (biomass to liquid). Correspondingly, liquids produced from natural gas are called GTL (gas to liquid) and from coal CTL (coal to liquid). Today, there are no commercial biomass gasification plants.

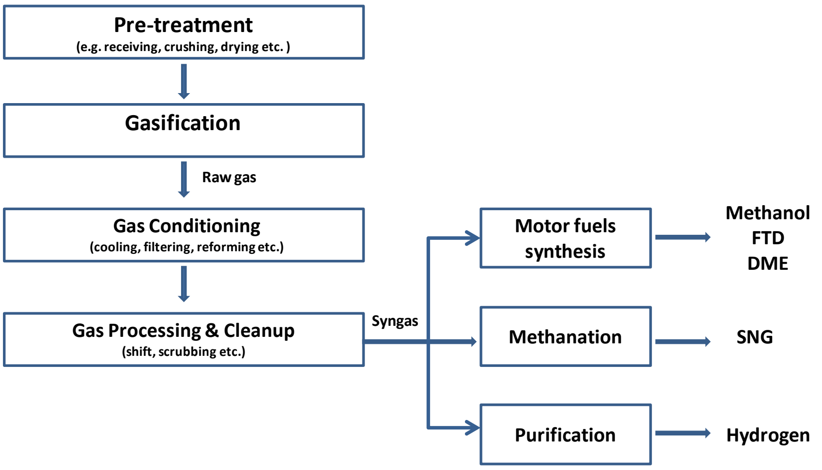

Figure 5. The key steps for syngas production and the different steps for converting this gas into final transportation fuel.

[84] SEKAB, site: www.sekab.com

2.3.5.1 SNG

Synthetic natural gas (SNG) can be produced from both fossil fuels and biomass. The main component is methane and it is produced through gasification followed by methanation. SNG can be used in the same way as natural gas and be mixed with natural gas when distributed in a gas grid. When SNG is used as a transportation fuel or when it is injected into a natural gas grid, the crude SNG must be upgraded through the removal of carbon dioxide and water.[85]

The Gothenburg Biomass Gasification project in Sweden, run by the district heating company Göteborg Energi and E.ON are building a thermo-gasification plant using biomass as the feedstock for SNG production. The plant will be built in two stages. The first stage is planned to be in operation by 2012 and will include a 20 MW gasifier. The second stage is planned to be in operation by 2016 and include a 80 MW gasifier.[86]

2.3.5.2 DME

Dimethyl ether (DME) can be produced through the synthesis of syngas. DME is a gas when it is held under normal pressure and temperature, but when it is compressed to a pressure of 5 bars, DME is in liquid form. DME can be used as a fuel in modified diesel engines and has many advantages; it has a high efficiency in modified diesel engines, and it is not toxic. However, it is highly flammable.

2.3.5.3 Methanol

When producing methanol from syngas, the gas is purified and treated and should have has a ratio of H_2 to CO that is just above 2. The reaction is taking place over a catalyst in a methanol reactor. Earlier catalyzing reactors where based on Zn/Cr catalysts and working at a temperature of 350 degrees Celsius and at a pressure of 250-350 bar. Due to improved gas purifying techniques, catalyzing agents based on Cu/Zn/Al can be used today, although these catalysts are more sensitive to contaminations. Because of this the temperature as well as the pressure is lower in modern methanol reactors, about 220-270 degrees Celsius and 50-100 bar. The resulting methanol is separated through cooling and condensation and contains about 5 percent water as well as by-products such as DME. The liquid is therefore purified through distillation in three stages, using a vapour-cooled reactor.[87]

2.3.5.4 FT-diesel

FT-diesel (Fischer–Tropsch diesel) is one of many names of synthetic diesel produced from biomass or natural gas. In comparison with conventional diesel FT-diesel has a smaller amount of aromatic compounds. In the FT process, carbon monoxide reacts with hydrogen over a catalyst, typically based on iron or cobolt.

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[85] Gode et al., (2008), Efficient production of biofuels for transport, Swedish District Heating Association

[86] Göteborg Energi, site: www.goteborgenergi.se

[87] Goldschmidt, B., (2005), Biobränslebaserade energikombinat med tillverkning av drivmedel, Värmeforsk (Swedish)

This forms liquid aliphatic straight-chain hydrocarbons (C_xH_y). This product is then refined to produce FT-diesel.

Hydrocarbons from the FT process are synthetic hydrocarbons. The FT process can be used to produce both synthetic diesel and gasoline; the latter process is less efficient, since the yield is smaller and the efficiency in the automotive engine is lower.[88]

Characteristic for FT-diesel is that it is free from sulphur and aromatic compounds and that it can be used in a regular diesel vehicle. FT-diesel has higher energy content per volume than regular diesel and it is fully mixable with regular diesel.[89]

In Finland, NSE Biofuels Ltd together with Stora Enso and Neste Oil has a demonstration plant at Varkaus for biomass to liquids production utilizing forestry residues. NSE Biofuels Ltd is focusing first on developing the technology and later commercial-scale production of biocrude for renewable diesel. The demonstration capacity includes a 12 MW gasifier. It is used to develop technologies and engineering solutions for a commercial-scale plant. The demonstration process unit is planned to cover all stages: drying of biomass, gasification, gas cleaning and testing of Fischer-Tropsch catalysts.[90]

Choren is a German technology company in Freiberg that is working with BtL (biomass to liquid). The company core competence is gasification, for which they have developed their own method that produces a synthesis gas that is free from tar. Choren cooperates with Shell for the production of FT-diesel. Their gasification process is connected to the FT-process of Shell to form a synthetic biofuel that they call SunDiesel. The process is also used commercially in Malaysia where Shell is producing FT-diesel from natural gas. The current facility that is being put into operation has a gasification efficiency of 45 MW. It is dimensioned to be able to produce 11000 tons of FT-diesel each year. Within a few years a new facility will be established. It is planned to be put into operation in 2015, having a capacity of 200.000 tons of FT-products each year.[91]

2.4 Non-technical project examples from the Ouestionnaries

There are some interesting projects going on in the Baltic Sea Region that don’t fit directly in the areas described in previous chapters. Some of them are described beneath.

2.4.1 Sustainable Energy

In March 2007, the European Council reaffirmed the Community´s long-term commitment to the EU-wide development of renewable energies beyond 2010. The European Council endorsed a binding target of a 20 % share of renewable energies in overall EU energy consumption by 2020 The decision also included a 10 % binding minimum target to be achieved by all Member States for the share of transport fuel from renewable sources.

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[88] ÅF
[89] ÅF
[90] Questionnaire, Finland, Demo site or pilot plant #1
[91] ÅF and CHOREN Industries, site: www.choren.com

EU leaders also established a directive (2009/28/EG) concerning sustainability criteria for biofuels. The directive includes requirements about the raw material that is used. No raw material from undisturbed forest, biodiversity grassland or nature protection areas are approved to be used. Some answers from the questionnaires mentioned their work with implementation of sustainability criteria for biofuels, for example the respondent from Latvia.

In Latvia, the State Enterprise Vides projekti has performed a project concerning implementation of sustainability criteria for biomass as well as elaboration of a supporting action plan. This was done to categorize the biomass resources in Latvia according to their potential to reduce GHG emissions and to estimate the potential of more intensive utilization of woody biomass for energy production. The project concluded that all types of forest biomass fulfil the criteria of limiting reduction of GHG emissions of at least 30%. [92]

Other respondents also mentioned their work with sustainable energy.

In Finland, the University of Helsinki runs a project called "Bioenergy, electricity and emission trading markets (BEET)". The project is part of the Sustainable Energy 2008-2011 – research program funded by The Academy of Finland. This consortium examines the chain of bioenergy production, the designs and effects of bioenergy policies and their interaction with related emission trading and climate policies. The consortium produces new knowledge on energy efficient and sustainable bioenergy production system by combining plant production, soil science and technological research with economics and policy analyses.[93]

2.4.2 Industrial Symbiosis or poly-generation

The idea behind an industrial symbiosis is to achieve the most efficient use of biomass raw materials by combining different processes or industries. For example, a district heating company can produce district heat and electricity as well as steam for an ethanol fermentation plant. There are some examples from the Baltic Sea Region regarding industrial symbiosis.

In the Danish city Kalundborg a cooperation between companies, called the Industrial Symbiosis, has been going on for more than three decades. The central idea is that wastes or by-products from one company can be valuable resources for another company. This cooperation stretches through a variety of fields, having in common that they have a positive impact on the environment as well as giving a positive economic result. At the present 25 different projects are going on. The Asnæs Power Plant is the largest power station in Denmark and it is used as a combined heat and power plant (CHP) that delivers to 400 GWh of steam per year to the three companies Statoil A/S Refinery, Novo Nordisk A/S and Novozymes A/S. Another example is the company Inbicon A/S that is building a bio-ethanol production facility close to Asnæs, where the heat from the Asnæs process steam will be used in the process. One of the challenges for the future for the Industrial Symbiosis is to include new energy sources, such as biomass or biogas, in the cooperation.[94]

[92] Questionnaire, Latvia (AZ), Research project # 1
[93] Questionnaire, Finland, research project # 2
[94] Industrial Symbiosis Institute, Kalundborg, New technologies and innovation through Industrial Symbiosis, (2008)

Skellefteå Kraft in Sweden combines modern wood pellet production with production of district heat and electricity at a high system efficiency.[95]

A poly generation plant is planned in Sveg, Sweden. There has been an idea, a vision about an ethanol producing plant in Sveg since about 1995.The main reason was that the biomass company, Härjedalens Miljöbränsle AB, already established in Sveg manufactured pellets and briquettes of wood and peat for heating plants and industries. Lignin, a by-product in the manufacture of ethanol from cellulose is extremely useful as a fuel and could be included in briquettes or pellets. Locating the ethanol factory next to the HMAB biofuel factory clearly provides an efficient use of resources. In 2006 the implementation of the idea started and NBE Sweden AB has now built a pilot plant where they and the Faculty of Chemical Engineering at Lund University of Technology are cooperating to optimise the extraction of ethanol on an industrial scale from various raw materials such as wood, straw and industrial hemp. Biogas can also be made from the by-products of the distillery (so called stillage). The ethanol plant and the factory for producing fuel briquettes and pellets are two of the corner-stones for their future plant. The third is a combined heat and power plant that will be fired mainly with by-products from the ethanol production. [96]

[95] Questionnaire, Sweden, research project #1
[96] NBE Sweden, site: www.nbesweden.com

3 Future bioenergy situation in the Baltic Sea Region

Chapter 2 presents a view of the present bioenergy situation in the Baltic Sea region based on the answers from the questionnaires. This chapter discusses the situation for the year 2020 and year 2050. The answers from the interviewees regarding their vision for the future bioenergy situation were in many cases very brief. Therefore, the answers from the questionnaire have been supplemented with ÅF knowledge.

3.1 Bioenergy situation in year 2020

The COP 15 meeting in Copenhagen was recently concluded. An agreement for a future climate regime could not be reached and disappointment has been expressed by many of the participants as well as the civil society. According to Olle Björk from the Swedish Ministry for Environment there were at least a few positive results from the meeting, and the process will continue within the next year[97] but it is still uncertain if an agreement will be made. However, regardless of a post-2012 climate agreement some trends can be seen and agreements and commitments on other levels that are sure to be strived towards.

In 2008 the European Union adopted the 20-20-20 Renewable Energy Directive. The aim of this directive is to (1) reduce greenhouse gas emissions by 20% (compared to 1990 emission levels), (2) reduce energy consumption with 20% and (3) increase usage of renewable energy with 20% until year 2020. These goals have resulted in mandatory targets for the EU member states. Bioenergy will play an important role to achieve these targets for all the EU member states as well as the non member states in the Baltic Sea region.

The interviewees were asked what bioenergy technologies they thought would be of importance by the year 2020 and how this would be achieved. This section summarizes and discusses the answers that were given.

One of the most difficult barriers to overcome is price competiveness. With low cost energy available on the market it is hard for bioenergy to compete, due to high production costs and other bioenergy related problems. Small scale production results in high production costs and difficulties to compete with fossil fuels. However, the production scale will not increase until there is a demand, and there will likely not be a demand until the costs decreases. According to the answers from the Finnish interviewee, the price competitiveness has to be overcome to reach the potential utilisation rate especially within the forest and agriculture based transportation fuels. However, this is also true for energy crops, which have high production costs due to small scale cultivation and high storage and transportation costs. In order to reduce the production costs it is not enough with only larger cultivation areas, the energy yield per hectare must also be increased and the

[97] Presentation at Energiledargruppen, Stockholm, 2010-01-14

infrastructure and transportation system have to be developed. Though, the increasing demand for a sustainable use and production of energy can be the driving force towards an increasing demand for biomass.

Political decisions and the economic situation are factors that will have an effect on the situation regarding bioenergy in year 2020. Many respondents mentioned this to be one of the most important factors for an increasing bioenergy usage. According to the Norwegian respondent, the policies have to be formulated and implemented with clear financial incentives, which support the development and promote equal share between classic energy supplies and new energy. The government's willingness to promote policies and development of the bioenergy sector are also said to be important factors. The Latvian respondent believes that a clear definition of the state policy according to renewable energy targets implemented in the investment and support scheme of agriculture, forestry, transport and energy sector is needed to support rational systems. This is necessary in order to avoid economically non-feasible systems. The Estonian respondent suggests more incentives for private investors and for the private forest owner to produce wood for energy.

When biomass is used for a variety of purposes in different market segments the price can rise due to an increased demand. Increased demand for certain crops does not only lead to an increase in price of those crops, it can also increase the price of other crops because they are competing for the same agricultural land. According to the Finnish respondent, it is important that the availability of bioenergy is secured and the competition between food and fuel has to be balanced.

The following discussion of the bioenergy situation in 2020 has been focused on three different aspects: availability, use and conversion technology.

3.1.1 Bioenergy availability

The bioenergy production is limited by the geographical prerequisites. In Denmark, for example, the available forest resources are very limited and regardless of the demand for biomass this is not likely to change. Agricultural crops for biofuel production are also limited in many countries since the arable land cannot expand.

Biomass material is used for a wide range of purposes other than energy, e.g. food, paper, etc. This can create a competition for biomass between different industry sectors. In other cases, the demand in one sector can be the foundation for production of side products suitable for energy production. According to the answers given in the questionnaire, this is the situation in Finland where the availability of bioenergy resources greatly depends on the future production of the forest industry as it consumes roundwood and at the same time generates side products which are suitable for energy production. These circumstances limit the possible development until 2020.

According to the Norwegian respondent there are several studies that “indicate that there are enough resources in Norway to achieve the Governmental goal of 14 TWh increase in the production of energy based on biomass resources by 2020”.

The efficiency of the harvesting of forest can be improved, and new assortments of the forest could be used for energy purposes, such as stumps. This could lead to an increased potential for bioenergy production from the forests. In Sweden this potential has been studied by many different researchers, organisations and authorities giving a range of different results from 10 TWh/year to 70 TWh/year in additional forest bioenergy by 2020 comparing to 28 TWh/year of forest bioenergy usage in Sweden today. In addition to new assortments, the biomass production rate could potentially be increased both for forest based bioenergy and agricultural bioenergy resulting in more available biomass for bioenergy purposes. Furthermore, the Latvian respondent claims that the uneven age structure of the forest in Latvia (and possibly other forest rich countries) will result in an increased harvesting of about 50% in the next decade if the current forest management techniques are kept.

3.1.2 Bioenergy use

The usage of bioenergy depends strongly on the availability. Political means of control are also important for the development. In Sweden the so called electricity certificate system rewards the production of renewable energy at the same time as it creates a demand, since it is mandatory for energy producers to obtain a certain amount of certificates. The Swedish respondent believes that this system needs a continued support in order for the bioenergy usage to develop further.

Combustion systems are mentioned by several interviewees. In Norway they are anticipating “new biomass combustion systems that allow the use of different energy sources” and in Estonia “waste burning power plants” are anticipated by year 2020. The Lithuanian respondent also thinks that an increased usage of combustion of municipal solid waste will be of importance.

In Finland the aim is to reach 38 percent renewable energy of the final energy consumption in year 2020. The main potential for achieving this, according to the interviewee, is to develop the combined heat and power production. In Norway the district heating system is also believed to be of importance and it is stated that “district heat systems and local heat plants will be the most common source of heat in Norwegian households” by 2020.

The potential of pellets is mentioned by two of the interviewees. The Norwegian as well as the Finish respondent are expecting new assortment of pellets with a wider raw material supply. According to Lennart Ljungblom at The Bioenergy International "If one can get the raw material situation under control, the logistics and stable political condition in the direction everything is pointing - then the pellet market will grow more than 10 times in volume up to 120 - 140 million tons per year" in Europe.[98]

The usage of bioenergy is also depending on the energy efficiency measures that can be implemented. A reduced and more efficient energy usage will increase the possibilities for a larger share of renewable energy. The German respondent points out that “[i]n general all technologies to improve energy efficiency in all sectors will be most important.”

3.1.3 Bioenergy conversion technology

There are great differences within the Baltic Sea region in how far the different countries have come in the development of bioenergy conversion techniques, and therefore the answers from the questionnaires varies a lot regarding the technology development in 2020. For example, Estonia is expecting waste fired power plants in 2020, which is already commercial in Sweden. Consequently, increased cooperation between the countries in the Baltic Sea region can speed up the development. Increased research in the bioenergy field will also be needed for the continuing development. In Norway “bioenergy related research and development program are expected to be higher than those targeting fossil fuel” by 2020. The respondent believes that “[b]y 2020 Norway will lead the production of 2nd generation biofuels and its commercialization”. Transportation is said to be based on a combination of biofuels and electricity. The usage of electricity in transport by 2020 is not mentioned by any of the other respondents. The German respondent believes that techniques for “biomass to liquid probably will get more importance in the transport sector. The future role depends on the successful development of this technology."[99] The Latvian as well as the Lithuanian respondent is hoping for biofuel produced from forest products. Biogas technology is mentioned by a few of the interviewees to be of importance, especially for the transport sector. The Finnish interviewee believes that biogas technology could have an important role as transportation fuel, as well as biodiesel. The Polish respondent is hoping for biogas plants that are integrated with fuel cells.

3.2 Bioenergy situation in year 2050

Naturally an analysis of the bioenergy situation in year 2020 will contain a lot of uncertainties, since many influencing decisions are not yet made. For the same reason, an analysis of the situation in year 2050 will be even more uncertain. Besides that, a longer time frame increases the possibilities for changes that are more difficult to predict, such as large scale societal changes, population growth, warfare and radical development in available technologies. Looking forty years back, the societal changes have been tremendous in many aspects.

[98] Ljungblom, L., (2009), The PelletsMap, The Bioenergy International
[99] Quote has been modified after discussion with interviewee.

The idea that a peak in the world oil extraction will soon occur is gaining increasing support. Some even believe that the peak is more of a plateau and that we are already there. The effects that this might have are hard to predict but fluctuating oil prices are likely and this might open windows of opportunities for other alternatives that otherwise would not occur.

Governments as well as larger companies often have developed long term goals for reducing their future energy usage and environmental impact, sometimes stretching as far as to the year 2050. In Sweden, for example, the present Government has declared that by year 2050 Sweden will not have any net emissions of greenhouse gases. Accounting for these goals is however beyond the scope of this report.

In the questionnaires the interviewees indicated what bioenergy technologies they thought would be of importance by the year 2050, as well as what was needed for this to happen. The responses were scarce and many of the respondents did not answer the question at all. The Estonian respondent concluded that "so far it is too hard to estimate the 2050 perspective", a statement that probably no one would argue with. Some interesting thoughts were however shared and are accounted for here. The answers given were not only focusing on the technology and were instead describing general thoughts about the situation in year 2050.

The Estonian respondent also mentioned that forest covers approximately 50 percent of Estonia. The forest sector is important in Estonia´s economy. Since a lot of bioenergy is coming from the forest or from forest industry products etc., it is clear that the future of bioenergy is linked with development of forestry and forest industry. Due to decreasing oil resources it can be assumed that the demand for other fuels increases and the pressure to achieve higher yield from the forest will increase. The Estonian respondent also pointed out that it is important to remember that besides the energy sector other industries also compete for wood resources. "Lot of research is needed in many different subjects. Lot of different scenarios, models have to be "played". Forest management more oriented to the energy production is one possible scenario."

The Finnish respondent believes that "agricultural residues and the use of liquid biofuels can have a notable role in primary energy consumption"[100] in Finland by the year 2050. According to an analysis being made it has been estimated that the use of wood fuels will increase and by year 2030 it will be 50-70 % higher than in 2005. After that the increase is however estimated to be limited. Altogether, the respondent concludes that "the availability of bioenergy resources greatly depends on the future production and development of the forest industry"[101].

The Norwegian interviewee states that the continuing development is dependent on strong universities and research and development programs "allowing the formation of qualified personnel needed to develop and maintain the bioenergy sector" in

[100] Quote has been modified after discussion with interviewee.
[101] Quote has been modified after discussion with interviewee.

combination with “policies and incentives promoting the development of bioenergy related activities”. It is also mentioned that institutional collaboration must be “strengthened among the energy stakeholders, such as politicians, R&D-groups, private industry, donors, agencies and the society”.

The Swedish respondent expects developed technology for renewable transportation fuels. This development is, however, considered to be dependent on a more advantageous price relation between fossil fuel and renewable fuels. Only the Norwegian respondent mentions the possibilities of electric vehicles instead of using liquid or gaseous renewable transportation fuels. The Norwegian respondent also answered that it is important with “second generation biorefineries that are developed on the basis of more sustainable derived biomass feedstocks”. Also “clean thermochemical and biological conversion technologies” that can produce a range of different energy carriers is expected.

Gasification is mentioned by both the Lithuanian and the Swedish interviewees as something that should be developed further. They refer to gasification of both biomass and waste products. During gasification a large amount of excess heat is produced. The Swedish interviewee, therefore, mentions that in order for development of cost efficient commercial scale gasification plants there is a need of a suitable size district heating infrastructure.

New biomass combustion systems are mentioned by the Norwegian respondent, in combination with low cost biomass fuels. The infrastructure, as well as efficient district heating and local heating systems is however thought to be in place already today.

The Latvian respondent, being from the Latvian State Forest Research Institute, is expecting a “continuous trend to develop short rotation forest and short rotation coppice, to provide biofuel and timber”. Also “genetic improvement of certain fast growing tree species to increase tolerance to diseases and climatic circumstances” is mentioned. This needs investments in research and development together with reforestation already today, since these forests will be harvested and will sequestrate carbon in 2050.

There are many different technologies that have a potential to develop until the year 2050. The focus of this report is on bioenergy, but there are also many other technologies that have the possibilities to develop within such timeframe. Solar energy is mentioned by both the Lithuanian and the Norwegian interviewees as an important technology for the future, for both electricity and heat production. Other important developing technologies for renewable electricity production are wind power and wave power. These technologies are not within the limits of this report. However, the development of these renewable energy sources may influence the future of bioenergy in many ways. For example, an increased electricity production may facilitate the development of electric cars and thereby compete with the utilization of liquid biofuels.

4 Summary and Conclusions

The questionnaires indicate many interesting aspects of the bioenergy situation in the Baltic Sea region. However, conclusions from this material must be handled carefully since it is based on a limited selection of representatives within the region. It is also important to consider that the interviewees often represent a certain field of interest and thereby can be assumed to favor their own field. In combination with ÅF in-house expertise some interesting results can however be presented from this material.

In general the questionnaires give a first glimpse of what is currently taking place within the bioenergy field, and what is envisioned for the future. It is obvious from this material that there are large differences between the countries regarding the techniques that are being used as well as anticipated in the future. Some countries are aiming for technologies that are already commercial and very common in other parts of the Baltic Sea region.

The graph below presents the current development of different bioenergy technologies. Examples are given of countries in the Baltic Sea region that are at the frontier of this development.

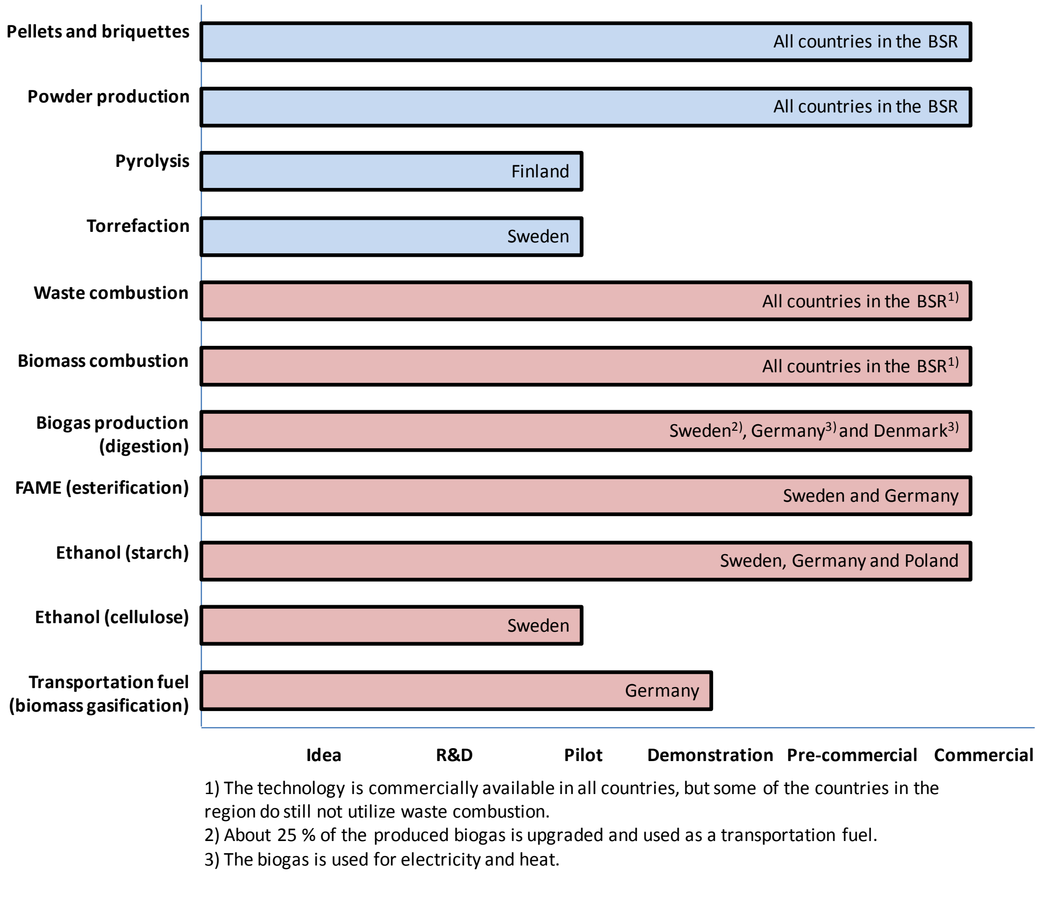

Figure 6. Development of bioenergy technologies and examples of countries in the Baltic Sea region that are at the frontier of the development.

4.1 Present and expected future for years 2020 and 2050 regarding bioenergy use

The COP 15 in Copenhagen has recently finished without achieving an agreement. However, the Kyoto protocol took several years of discussion before being entered into force and the meeting in Copenhagen was possibly the starting point of a similar process. A post-2012 agreement with ambitious goals would likely have a heavy influence on the countries in the Baltic Sea region and the development of bioenergy usage.

Regardless of any international climate agreements being made, the EU 20-20-20 Renewable Energy Directive will influence most countries within the Baltic Sea region (Norway and Belarus are not EU members). This is likely to influence the usage of bioenergy in many ways such as (1) increasing the competition for biomass as raw material for energy purposes, (2) forcing a development of new assortments of raw material and (3) continued development of renewable transportation fuels, which all have been indicated in the questionnaires.

The present bioenergy situation varies greatly between the investigated countries. This is illustrated by the tables that were presented in this report, showing the enormous differences between the countries in terms of bioenergy production. The different vision for the future between the respondents is also notable since all of them present a view that differed from all the others distinctly. This might however be a result of the different background of the interviewees.

The usage of bioenergy is to a large extent influenced by the available resources. Not all arable land can be used for bioenergy purposes, not only because the circumstances must be right for cultivation and plantation, but also because there is a competition for the available land. It is not evident whether the cultivation of food crops or energy crops should be prioritized. There is also competition for raw material that can be used either as energy source or for other purposes. For example, wood can be used for the pulp and paper industry or sawmills and oil crops can be used for food production. Therefore, it is crucial to use these limited resources efficiently as well as to develop new assortments of raw material and increasing the yield during harvesting and usage.

4.2 Common and different development objectives

Looking at the responses from the questionnaires it is difficult to find common and different development objectives other than the obvious overall common objectives such as (1) reducing green house gas emissions, (2) increasing the competiveness of the business, and (3) decreasing the dependence of oil from unstable regions. The development process seen in the questionnaires can roughly be divided into three steps. The first step is normally towards the heating sector, by increasing the bioenergy usage in this sector and thereby developing the infrastructure for bioenergy usage. The second step has been to convert the power production towards using renewable energy sources, e.g., biomass and wind. The final step, and the most challenging, is to convert the transport sector from its heavy dependence on fossil fuels to renewable fuels. When different development objectives have been found, it is likely related to the stage of development in each country.

4.3 Project results of special interest

As being mentioned above the discrepancy in the responses is noticeable. Countries being geographically close to each other could be thought to have similar preconditions and also having similar visions for the future. Based on the questionnaires this is far from the case.

In many of the projects that are presented in the questionnaires there are participants from several countries involved. It is also common with participants from different fields, such as industry representatives, forest owners and universities, working together in the same project. This type of cooperation might have an important role for technology transfer today as well as in the future. An example from the questionnaires of this kind of cooperation is the project “Extraction of logging residues at LVM”, where the Forest Research Institute of Sweden together with the Latvian State Forest Research Institute has performed a project in Latvia a few years ago[102]. Another example is the project “Enhancement of the Use of Local and Renewable Energy Sources” that took place in Lithuania and dealt with a large number of issues regarding renewable energy.[103] This is an example of collaboration between the Danish Energy Management, local consultants and UAB Ekostrategija.

4.4 Future joint efforts and prohibitive factors

Prohibitive factors for the bioenergy development differ substantially between the different countries. Some countries lack the infrastructure needed for developing their bioenergy usage, while others lack the technology or knowledge.

Transportation is a field where all countries need to develop further. There are different possible fuels that can play an important role but further development is needed both regarding fuel production as well as vehicle and engine construction. In some of the countries in the region there is a well developed natural gas grid. This can be used for biogas and thereby facilitates the conversion to biogas in the future. Countries that do not have a natural gas grid, for example Sweden that only have a grid in the south western part, might need to expand their grid or use liquefied forms of biogas, in order to successfully increase the use of biogas as transportation fuel.

Another type of infrastructural challenge is the development of district heating system. Most of the countries in the Baltic Sea region have a well establish use of district heating. However, a continued development and restoration of district

[102] Questionnaire, Latvia, research project #1
[103] Questionnaire, Lithuania, research project #2

heating is crucial for continued development of biomass based large scale combined heat and power production. Finally, collaboration between the countries has been found to be wide spread and often very fruitful for successful technology transfer. This is considered to be crucial for further development in the region.

4.5 Conclusion and recommendations

Even though the questionnaires are a limited material, it is safe to conclude that there is a great potential for cooperation between the countries in the Baltic Sea region for the future. Cooperative projects are taking place already, with actors from different countries and backgrounds, but to speed up the technology transfer this should develop further. Energy efficiency is only briefly mentioned in the questionnaires but is sure to play an important role in the future development. Simply increasing the usage of bioenergy will not lead to a sustainable energy system unless it is accompanied with increased efficiency.

For future studies it would be interesting to investigate in further detail the availability and consumption of bioenergy in each of the countries in the region. An accurate mapping would however acquire a lot of statistical work, which was beyond the scope of this study. Governments and larger companies often have their own objectives and visions for their future achievements regarding energy usage. A compilation of these objectives would give an interesting picture of the aim for the future development and how these differ between the countries in the Baltic Sea Region. It would also be of importance to evaluate if these visions are realistic, in terms of available technology as well as resources, when comparing objectives from different governments and industries.

In conclusion, the respondents seem to have a positive view of the future for bioenergy and are all actively working towards more renewable energy dependence.