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"Optimal" use of biomass for energy in Europe:

Consideration based upon the value of biomass for CO_2 emission reduction

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Abstract

Europe is struggling to reduce its CO_2 emissions and to fulfil commitments made according to Kyoto protocol. At the same time, Europe does not possess enough fossil energy resources to cover its needs and thus consumption of imported fossil fuels is growing, placing threats upon economic stability. In order to combat these challenges, renewable energy sources and biomass in particular are expected to be wider spread and play a more significant role in Europe's energy mix in the future.

A wide choice of biomass sources is available to pursue – as are a range of conversion mechanisms. Biomass fuel chains contain, as the main steps, feedstock production, feedstock processing and the use of final product. The number of possible conversion routes gives different possibilities of carbon emission reduction with different contribution to security of energy supply. Installation and production costs also vary among the options. So, the question about "optimal" allocation of biomass pursuing carbon emission reduction is arising.

This thesis examines biomass utilisation in the energy sector for heat, electricity and liquid biofuel production. The study reveals the policy options that exist to support a biomass allocation that can be considered as the most desirable.

Executive Summary

The majority of energy consumed in Europe has fossil origins and the environmental impact of energy sector is large. In addition to the pollutants that fossil fuels emit when burning, they release also CO_2, which is a green house gas, thus contributing to climate change.

Another issue related to fossils fuel consumption is security of energy supply. The import of fossil fuels in Europe is large and is increasing over time. There are two main reasons for importing fuels: oil and natural gas are imported because of a European resource deficit; coal is imported because import prices are lower compared to the costs of coal extraction from the European coal mines.

EU has committed itself to reduce its CO_2 emissions by 8% by 2010 compared to the level of 1990. One important pathway is to utilise biomass. Contribution of biomass to CO_2 emission reductions and security of energy supply in Europe is discussed in the study.

There are three basic markets for biomass application: heat, electricity and automotive fuel. They all have different potential to influence CO_2 emission reduction. The actual effect depends on a combination of the energy crop chosen, the conversion technology or the conversion pathway. The policy measures are discussed for the most desirable, from carbon dioxide emission reduction point of view, biomass allocation option.

A number of biomass conversion pathways are available according to the feedstock used. Among the varieties of biomass, dedicated energy crops are worth a special attention, though crops traditionally used for other than energy purposes can also be adapted for energy production. Because of competition for land, which can be used for a wide range of goals, parameters such as high yield and significant overweighing of the energy output over energy input are probably the main ones that justify the use of land for growing of energy crops.

Crops with ratio output/input lower than 2 (oil and ethanol crops, excluding sugar beet) most likely cannot be considered as viable energy crops. For the crops that are not usually associated with bioenergy, such as for food, in the most cases, outputs are low. Crops with low output are valid for other (food, forage, fibres) but not energy purposes. The fact that output/input ratios for crops that are used as solid biofuel are much higher than for liquid biofuels indicates that from an environmental point of view, solid biofuel has much higher benefits than liquid biofuels.

The conversion pathways of biomass into heat, power and automotive fuels are also considered in this thesis. Direct biomass combustion, including co-firing with fossil fuel, and the gasification are utilised for heat and electricity generation. Electricity generation from biomass via combustion and steam cycle is a well established technology. Co-firing of biomass with fossil fuel (generally coal) in thermoelectric power stations is a simple and efficient method of energy generation.

The gasification route is applied in several market segments of which Integrated Gasification and Combined Cycle (IGCC) for Power is the most interesting. It is a combination of gasification process with heat and power co-generation. Gasification is flexible in the fuels used and in combination with CHP can generate almost as much as twice more electricity compared to boiler systems. Estimated efficiency is around 44-50%. The energy ratio output/input of a biomass fuel chain ending in IGCC with gas and steam turbines is calculated to be 8 for just electricity production and 15 if case of combined heat and power generation.

The use of biomass as a substitute for coal provides direct carbon emission reduction 0.5-0.6 tonne of C per each of biomass used or 0.8 tonne of coal substituted. Assuming annual yield of biomass feedstock from dedicated plantations at 10 dry tonne per hectare, each hectare can save 5-6 tonne of carbon (18-22 tonne of CO_2). In such instances, net CO_2 emission of biomass-to-power chain constitutes around 5% of coal-to-power chain.

Several pathways for automotive fuel production are available, however, only a few are technologically developed and are on commercial scale at the present time. They are the etherification of vegetable oil for biodiesel production and fermentation of sugar/starch containing crops for ethanol production.

Net renewable energy content of biodiesel (RME) in the final product is 65-70%. The use of 1 tonne of biodiesel instead of fossil diesel results in around 2-2.5 tonne of CO_2 emissions avoidance. Net renewable content of ethanol from wheat is just on 20-40% depending on system efficiency.

So, considering carbon emission reduction, the most beneficial use of biomass energy with current available conversion technologies is heat and power generation. This conversion pathway offers the best route for carbon dioxide emission reduction. Combined heat and power generation gives the most complex and efficient use of biomass resources. If Europe is serious about aiming for a 8% CO_2 emission reduction by 2010 compared to 1990, then a rapid reduction of fossil fuel use is required. Co-firing is a solution for the fast expansion of biomass-derived power through existing coal-fired plants.

However, under a scenario of maximization of carbon emission reduction, biomass will be used as a solid fuel in power plants and will substitute coal, reserves of which in Europe are abundant. Thus, when contributing to CO_2 emission reduction, biomass in this way will not significantly affect security of energy supply.

If Europe is most concerned about establishing security of energy supply, priorities of biomass application should be changed towards production of biofuel for the transport sector in order to replace oil and reduce its import into EU. However, this biomass allocation option is not cost-effective in short term due to the high production costs of biofuels. If the region attempted to reduce carbon emission by only automotive fuel substitution, Europe most likely will not be able to reach its target by 2010 because it will not be possible to introduce such a significant amount of liquid biofuels into the market in short term due to higher production cost of biofuel compared to fossil petrol and diesel.

Bioelectricity, as well as electricity from other renewable energy sources, requires legislative and financial support. Taxation of carbon emissions, GHGs emission trading can improve the economics of bioenergy production. Financial measures like aids, tax deduction and financial support would promote rather ambitious EU's targets regarding share of biomass in particular and renewables in general in energy generation. The very promising mechanism to help EU Member States to fulfil their obligations of renewable energy consumption is a combination of targeting with international renewable electricity trading. The extent to which renewable energy is exploited is likely to be determined by cumulative effect of supportive measures.

There exist EU directives with targets for renewable electricity and automotive fuels. With carbon emission quota system, it is not difficult to create policy measures for efficient CO_2 emission reduction. However, it is much more difficult to design policy measures to influence security of energy supply.

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1 Introduction

1.1 Background

Energy is a key issue for social and economic well-being. During a long period of time energy consumption has been a measure of development level of economy with oil consumption as a main indicator (Flavin, Lenssen, 1994, p.30). Why oil? Because 41% of energy supplied in Europe comes from oil and oil products. The state of world's economy depends directly on oil prices. While energy is an essential condition for provision of personal comfort, running industrial activities and commercial wealth generation, its generation and consumption put substantial pressure on the environment, contributing to "climate change, damaging natural ecosystems, tarnishing the built environment and causing adverse effects to human health" (European Environmental Agency, 2002). Among the wide range of goals of EU energy policy the main ones are security of supply, competitiveness and environmental protection (Commission of the European Communities COM(2002) 321 final). In environmental context, energy policy aims reduction the environmental impact of energy production and use, promotion energy saving and energy efficiency and increase the share of production and use of cleaner energy (Commission Communication COM(1998)571). All these areas are strongly interconnected: improvement in energy efficiency reduces energy consumption, contributing to security of energy supply, and reduces fossil fuel consumption, cutting down greenhouse gases emissions.

Despite the many technical advantages of fossil fuels, they have three very strong disadvantages:

- they emit pollutants when burning;
- contribute to climate change;
- economy of countries without enough reserves of fossil fuels to cover their needs of primary energy resources is under threat of interruption of energy sources supply.

Security of energy supply implies on availability of energy at any time in sufficient quantity at affordable price (European Communities, 2002a). Because fossil fuel resources, which countries rely on, are distributed unevenly on the globe and countries possess unequal capacities to develop other energy resources, energy security becomes a crucial issue (European Commission, 2001b). Several factors can influence the security of future provision of oil: growing global consumption of oil, mainly imported from the Middle East and thus growing demand; increasing dependence of industrialised countries on oil; potential conflicts, sabotages, terrorist actions, disruption of trade and reduction of oil reserves can also hurt global as well as national and regional energy systems (Johansson, Goldemberg, 2002, p.32).

Today ecological concerns are a major determinant of energy agenda, especially the problem of climate change (European Parliament COM(1998)571 - C4-0040/99). The scientific community is in wide agreement that global warming has adverse effects on our planet, causing a range of problems such as more unpredictable weather changes, heavy rainfall, rise in sea level, drought, forest fires (European Commission, 2001a; Flavin, Lenssen, 1994, p.63). "CO_2 is the gas primarily responsible for climate change. 94% of CO_2 emissions generated in Europe can be attributed to the energy sector in general and in particular to fossil fuels like petrol, coal and natural gas." (European Commission, 2001c). EU achieved its commitment to stabilise carbon dioxide emissions in 2000 at 1990 levels and reached 3.5% reduction (EEA, 2002b). However, it will be difficult for the EU to meet its Kyoto Protocol target of reducing total greenhouse gas emissions by 8 % from 1990 levels by 2010. The major reduction of CO_2 emission happened in non-energy related sectors while energy-related emissions increased with the main contribution of transport sector (EEA, 2002b). The transport sector currently generates 28% of European CO_2 emissions but it is also the sector responsible for 90% of the increase in emissions between 1990 and 2010 (Commission Communication COM(2002) 321 final). Total emissions in 2010 are likely to be about the same as in 1990 unless additional measures are taken. Moreover, according to projections of the European Environmental Agency the total gas emissions of the member states will increase by at least 5.2% between 1990 and 2010 (European Commission, 2001c).

Energy efficiency has increased, which was one of the main factors making possible CO_2 emissions reduction in period 1990-2000. But the trend is growing energy consumption. The growing well-being of Europeans leads to higher energy demand, in particular electricity, currently mostly bound to fossil fuel combustion. Bioenergy together with other renewables is expected to become one of the key energy resources to combat global warming and exhaustion of fossil fuel resources. Today, more efficient use of energy is a cheaper way of GHGs emissions reduction than investment in development of renewable energy sources (European Commission, 1999). But those investments are vital from the long-term perspectives.

Over three decades from the oil crisis of the 70s the notion of energy security has taken on a wider meaning. It is not just matter of reduction of import dependence and promotion of domestic production. Now it incorporates diversification of energy sources and technologies, including renewables in addition to fossil fuels with support of policy initiatives. It implies more efficient use of energy, ensuring the smooth operation of markets. Above all, environment is an essential component of energy security.

EU directives set targets of a certain percentage of biofuel in automotive fuels and in heat and electricity production that should be reached till 2010 in order to fulfil obligations regarding CO_2 emission reduction taken by signing Kyoto protocol and to guarantee the energy security supply in the future, decreasing dependence on imported oil. There are three basic markets for biomass application with different potential to influence CO_2 emission reduction. Biomass can be processed into a number of liquid fuels, can be combusted or co-combusted with fossil fuel or gasified and burned for heat and electricity generation. The actual effect depends on an energy crop chosen, conversion technology. Decision makers don't have a good base to choose which route they should prioritise. All conversion pathways vary in possible contribution to the security of energy supply. There are significant differences in energy yield per unit of biomass. There are also large variations in scale of plants. Significant differences are also in employment opportunities per energy unit. But for making decision in this instance, the route that gives the highest carbon emission reduction per unit of energy service provision is considered the most useful. The question which of the routes gives higher CO_2 emission reduction should be investigated.

1.2 Objectives of the study

For a long period of time human beings used fossil energy resources in increasing amounts without consideration of environmental consequences of such a use. Several decades ago scientists notice growth of concentration of CO_2 and other GHGs in the atmosphere, related to accelerated human activity. Since increased amount of such gases can cause climate change, the result of the worry was Kyoto protocol, according to which countries committed themselves by 2010 to reduce GHGs by 8% of the level of 1990. Energy and transport sectors are the ones that contribute to the total GHGs emission the most and where possibilities to reduce emissions exist due to a number of technical measures.

In this concern, biomass as a renewable energy source starts playing an increasingly important role. Biomass through a number of processing routes can be converted into heat, electricity or liquid fuel to power vehicles. Carbon emission released during combustion is balanced by the natural process of carbon sequestration by green parts of plants, by roots etc, on the contrary to carbon of fossil origin. In any of biomass application options, e.g. for liquid biofuel production, a certain amount of fossil fuel is used, for instance, on crop cultivation stage (on-field machinery operations, fertiliser and pesticide production), harvest delivery, feedstock processing. Thus, biomass derived heat, electricity and fuel are not 100% fossil free. The exact potential of each option to reduce carbon emission depends on a number of factors such as the energy crop chosen as a feedstock, conversion route, processing technology, its maturity and possibility to improve, finally total efficiency of the cycle, its optimisation that also depends on management issues.

The aim of this study is to provide the basic information for policy makers in the field of biomass energy in order to achieve environmental and economic stability in energy sector.

The objectives of present study can be expressed as following:

1. to define crops used now or potential to be used as energy crops, having the highest possibility to substitute fossil fuels in energy sector;

2. to consider optimal allocation of biomass (heat/power generation application vs. liquid biofuel production), e.g. to define the value of each possible conversion route of biomass to energy in terms of contribution to CO_2 emission reduction and to figure out what is the preferable option;

3. to identify policy options promoting the most attractive, from CO_2 emission reduction point of view, biomass application.

The named objectives can be transformed in the following research questions:

1. what is the "optimal" allocation of biomass resources pursuing carbon emission reduction and security of energy supply;

2. which policy instruments exist for promotion of a biomass application option that is the most desirable for carbon emission reduction?

1.3 Scope

The present paper is Europe specific. Specificity lies in energy crop chosen for consideration, and promoting policies. All data are presented for EU-15 due to availability of comprehensive information for older Member States (before May 1 2004), however, some data for EU-25, especially in projection of future energy demand, is also presented.

Dedicated plantations have been cited in special literature as one of the largest potential sources of biomass in the future. "Any significant level of biomass energy provision will need to rely on energy crops" (Bauen, Woods and Hailes, 2004). Agricultural and forest residues, cannot be expected to cover increasing demand for biomass fuels in the future. Agri and forest residues constitute a large part of total stream of harvested material. For instance, wheat grain and straw have almost equal weight, meaning that straw constitutes half of harvested material. Usually such residues have very little, if any, economic value and present very cheap feedstock for energy production. However, crops like wheat or rape were primary cultivated for food production and thus were bred to maximize the grain/seed yield, but not the total biomass yield, unlike to energy dedicated crops. So, one challenge is that pursuing high grain yield and biomass yield are different tasks. It may be difficult to plan and rely on waste stream as a biomass input for energy generation.

Another constrain lies in the fact that utilisation of such residues can result in soil degradation since small branches, peens and needles contain a lot of nutrients, which in case of removal of residues from the land will be taken away from the soil. Food crops require relatively high input of fertilisers and pesticides. Mineral nutrients from fertilisers will be extracted from the soil with straw and end up in air with exhausted gases during combustion.

Municipal, which is also considered as biomass, is not considered in this paper. One of EU policies aims the increase of the share of biomass in primary energy sources that means more biomass is required. At the same moment, the EU desire is waste minimisation that means less waste should be generated. Considering these two directions, municipal waste most likely may be important biomass feedstock only on the local level.

Hence, this paper considers dedicated energy plantations, like short rotation coppices, herbaceous plants, and crops that can be alternatively used for energy and food production (for instance, cereals) as an input for heat, electricity and liquid fuel production.

Limitation of this paper is that energy balance, presented for a range of crops, varies from region to region in Europe, reflecting current agricultural practice. So, displayed figures, even if they are given as a range, can differ from the ones for a concrete area. Energy balance of heat, electricity and liquid fuel production is largely influenced by credits given to by-products, generated in parallel with main material flow, which, in turn, depends how these by-products will be used: as a solid fuel to run the main process of biofuel production, as an input for non-energy purposes, animal feed etc. The question what kind of energy crop to choose depends on not only energy balance of each crop and production costs, but also on environmental implication of energy crop cultivation, environmental burden of such plantation (for example, its impact on soil erosion, or requirement of pesticides and fertilizers, impact on ground water level). This results in the fact that against a set of environmental factors, the same crop can be desirable in one area of Europe and posting environmental threat (for instance, causing ground water depletion, or acidification) in another.

Nuclear energy is not covered in this paper for a number of reasons. Nuclear energy is relatively clean in terms of CO_2 emissions, where fossil fuel is used for uranium ore extraction and used fuel reprocessing, but carbon dioxide almost is not emitted during power generation stage (Miller, 2004). Moreover, nuclear energy actually helps to cut carbon emission by substituting fossil fuel use for electricity generation (Watson, Zinyowera, Moss, 1996). More than 40 000 MWh of electricity is possible to produce from 1 tonne of uranium, that otherwise, in case of fossil fuel, would require 16 000 tonne of black coal or 80 000 barrels of oil. But even if nuclear energy plays considerable role in electricity production, due to further problems with decommissioning of old nuclear plants, still unsolved problems with radioactive waste, security reasons and fallen public acceptance, current general trend towards decreasing the share of nuclear energy in total European energy production and use is forecasted (European Commission, 2001a).

With regard to policy issues, EU level policy mechanisms create framework in which the Member States should develop their own nation specific instruments. The study covers EU directives, White and Green Papers. The ways how proposed actions are implemented on the national level, are not considered, though some country specific information is presented in Appendix 6.

1.4 Methodology

1.4.1 Research design

Energy sector could develop in several directions depending on strategy chosen. Minimisation of installation cost is one possible strategy that influences future development of the energy sector. Two others are minimisation of CO_2 emissions and securing of energy supply for the future. Strictly holding on only one of these strategies, the society will get three totally different results of structure of energy sector.

In the first case, minimised installation cost would be bound to better, more equal distribution of energy production facilities. Minimisation would also mean higher production costs that could be offset by lower transportation costs for delivery of feedstock and distribution of energy.

In the second case, to minimise CO_2 emission, society would need to promote energy saving technology development, forget about cost saving and completely switch to renewable primary energy sources, that would drastically rise the cost of energy. It, however, to a greater degree would slow down economic growth.

Putting the third scenario at the top, the use of coal as the most abundant (in the world and in Europe in particular) and relatively cheap energy source should be highly promoted. Development of coal combustion technologies would lead to decreasing of CO_2 emission per unit of energy generated, though in total, carbon emission from energy sector would be high.

Obviously, none of these scenarios will happen in pure form in the future. Solution is located somewhere in-between of possible options: with reasonable plant size, depending in each case on local conditions, with certain percentage of renewables in primary energy sources and clean-up technologies of exhaust gases neutralisation for plants where fossil fuel is utilised. It would be difficult for this limited study to cope with all three options simultaneously, so for simplification purposes, starting point of this paper is CO_2 emission reduction as a result of biomass utilisation.

Strategic optimisation paradigm is used. High carbon emission reduction should not entail excessive costs, meaning that each biomass conversion technology is weighted against installation and production costs. A very expensive total fossil free variant will unlikely be a viable option to be commercially implemented in the short-medium perspective.

1.4.2 Data collection

Secondary sources were used to collect data. Secondary data were obtained from ELIN (Electronic Library Information Navigator) data base, database ScienceDirect (journals published by Elsevier Science), publication of Organisation for Economic Co-operation and Development (OECD), International Energy Agency (IEA), European Environment Agency (EEA), using key words: biomass, energy crops, bioenergy, energy consumption, CO_2 emission, carbon sequestration, CHP, co-firing and agricultural policy. Materials of recently carried out conferences about renewable energy technologies and their promotion were also used. The main source of statistical data was Eurostat – statistical bureau of European Commission. Primary sources (interview via e-mail) were used to clarify disputable ideas and data displayed in the published materials, and to verify the information from secondary sources. The triangulation method of data validation was used that also contributed to confidence in the results (Silverman, 1993). In this method, data obtained from internet web pages, peer reviewed journals and university researchers is cross-checked.

Energy crop selection is based on the data for current situation. Area cultivated, yield and potential for improvement are the major factors determined the choice of crops to be covered by this paper. The most of perspective high yield crops are cultivated in small experimental fields, so data presented in the paper is based on literature review and personal communication with specialists.

1.4.3 Data analysis

Gathered data from all sources was analysed according to its content. In this method, data was were categorised based on three main area - agriculture, processing technology and policy instruments.

1.5 Thesis outline

The thesis consists of six Chapters and six Appendices.

Chapter 1 is devoted to introduction of the reader to the problem statement and to justify the focus of the research. It clarifies the research methodology and presents the design of the present study.

Chapter 2 is dedicated to description of energy market of the European Union. It shows the high dependency of EU countries on imported fossil fuel, first of all on oil and displays the potential of biomass resources to play considerable role in the EU energy mix.

Chapter 3 discusses different crops that are currently used or are perspective to be used for energy purposes. Crops are compared against energy input required, energy output, energy gain, cost issues and environmental impact of crops during cultivation.

Chapter 4 provides overview of biomass conversion technologies. Several processing routes are presented: utilisation for heat and power generation trough direct combustion, co-firing with fossil fuel and gasification; processing into liquid biofuels for vehicles through esterification (for oily crops), fermentation (for sugar and starch containing crops as well as for cellulosic crops with a certain pre-treatment) or thermal treatment. Finally, this chapter evaluates considered processing ways of biomass, comparing their possibility to reduce carbon emission substitute the fossil fuel, as well as installation and production costs in order to define which of possible options are more attractive.

Chapter 5 explores what policies exist in EU to support the implementation of attractive options.

Chapter 6 summarises findings of this study and makes recommendations with regard to further development of energy crops, technologies and policies

2 Overview of the Energy market in Europe

The future of European's economy depends on sustainable energy supply in terms of continuity, affordable price and ecologically friendly way of generation. European countries are relatively poor in fossil energy sources having only 2.0% of the oil, 3.5% of the natural gas and 12.4% of the coal world's reserves (European Commission, 2001b). Debates around security of supply were shaped by growing awareness about global and local environmental consequences of energy production and use (Commission Communication COM(2002) 321 final). Energy in any form, when it is generated or used, creates impact on surrounding nature in terms of transport, by-products and waste.

Security of supply has to be considered in the context of EU enlargement, environmental problems, climate change, sustainable development, economy and fiscal framework, internal energy market and globalisation. An overview of energy market in Europe and its future will be made in Chapter 2 in relation to environmental problems, in light of contribution of different industries and types of consumed energy resources to European's CO_2 emissions.

2.1 Fossil fuel consumption and import

Current and projected in 2030 energy sources covering energy demand in Europe are presented on Figure 1 (European Commission, 2001a). Figures for 2030 are presented with assumption of continuation of current trends without any drastic changes in policies and technologies, and without any significant measures.

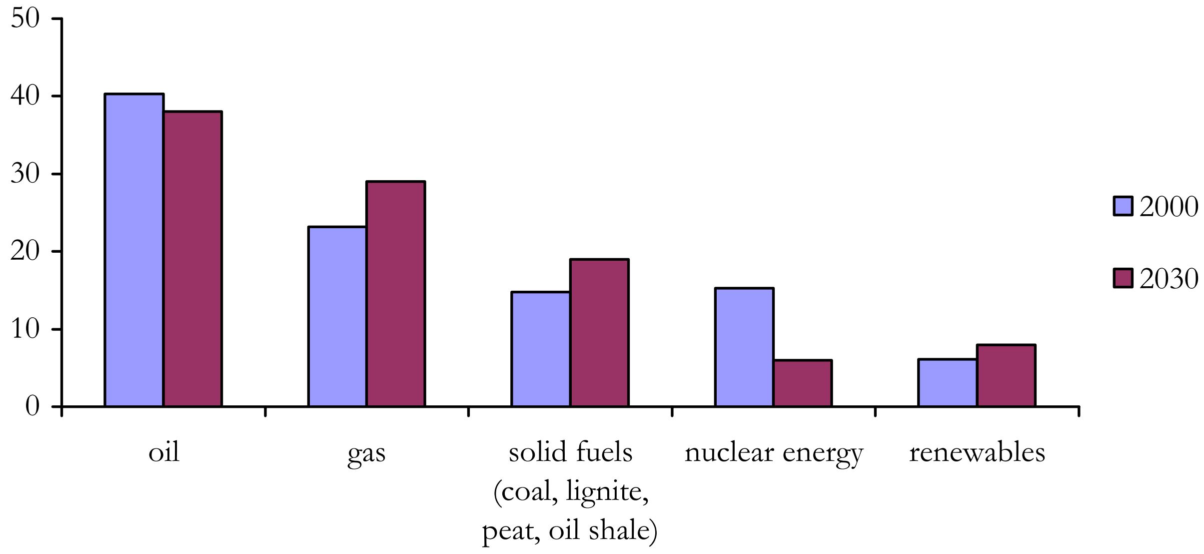

Figure 1 EU energy balance for 2000 (EU-15) and projected in 2030 (with regard to enlargement in 2004). (Source: European Commission, 2001a).

78.3% (in 2000) of energy used in Europe has fossil origin. Oil has the largest share in energy resources (40.3% or 588 Mtoe in 2000) (European Communities, 2003b) because of its high caloric value and ease to use. However, according to estimations, it is going to non-significantly fall in the future. Oil in Europe is extracted in the North Sea, where reserves constitute only 2% of world's ones at present. North Sea oil covers 21% of EU-15 oil demand. Among the Member States the United Kingdom is the larger producer of oil, covering 79.8% of the EU-15 total crude oil extraction in 2000 (European Communities, 2003b). The other supplier within EU is Denmark - 11.3% of EU's crude oil extraction. In fact, oil development in the North Sea is close to decline due to depletion of known oil reserves, expensive exploration of new resources and several times higher cost of oil extraction than in the Middle East (8-10 $US/barrel compared to 2-3 $US/barrel). Around 80% of oil used in Europe is imported mainly from OPEC countries (51%) and Russia (18%). However, EU deliberately sources oil from a nuber of suppliers in order to prevent negative effect on the overall economy in case of disruption of one of the sources. In the future EU oil import is projected by the European Commission to be around 90% of what is needed and European countries will become very dependent on external oil supply (European Commission, 2001b).

Crude oil is mainly used as input to refineries where it is split up into derivates: circa 35.5% diesel oil; 21.5% gasoline; 16.0% residual fuel oil; 6.8% kerosene and airplane fuel; 6.6% naphtha; 3.6% refinery gas; 3.1% of liquefied petroleum gases; 6.9% of other petroleum products (European Communities, 2003b).

Since the time of oil crisis in 70s oil was widely substituted by alternative fuels in stationary applications (industry, heat and electricity generation). The transport sector remains particularly dependant (98%) on oil supply as energy source, accounting more than 2/3 (69.7% in 2000) of oil consumption and its demand for oil continues to grow. Possibilities to substitute oil in transport are very limited. With no new technical solutions, alternative technologies, projections are that the transport sector will consume up to 65% of oil by 2020. Households' share of oil consumption was 12.8% in 2000 (European Communities, 2003b).

Natural gas consumption represents 23.2% (338 Mtoe) of EU gross inland energy consumption (European Communities, 2003b). Share of oil in covering EU energy demand stays relatively constant, while gas become more and more popular, gradually replacing solid fuel, coal in particular, and oil. There are several reasons for this:

- investment cost for gas powered plant is low compared to other fuel options, providing quick return of investment;
- higher efficiency in combine cycle plants for electricity generation;
- gas can satisfy many kind of energy services while having lower level of GHGs generation than in case of oil and coal utilisation;
- it is easily available from domestic EU's resources and from reservoirs nearby EU's border (European Commission, 2001b).

Unlike oil, gas reserves are distributed relatively well around the globe. The major reserves are located in former Soviet Union, Middle East, North Sea and North Africa, representing the most interesting regions for gas supply to Europe because of easy exploitation of these reserves and convenient shipping. According to estimations worldwide, it would be enough of gas supply for the nearest 60 years (estimations of 1999), however reserves will be observed to decline in 20 years (Bourdaire, 1999, 36). In Europe natural gas will run out in 20 years. EU's gas demand is covered by import from Russia (41.1%), Norway (23.3%) and Algeria (29.1%). Other important gas suppliers in EU are the UK and the Netherlands with 51.2% and 27.2% of EU's natural gas production respectively (European Communities, 2003b). After EU enlargement gas demand and import from Russia in particular is going to increase drastically due to the fact that new EU members historically were supplied by gas from former USSR. Total gas import is projected to rise from current 40% to 66% by 2020 (European Commission, 2001b). Growth of gas consumption is expected on two thirds to be allocated to power sector including CHP (European Communities, 2003b).

In the contrast to oil, most of gas (72.4% in 2000) is consumed directly by final customer, mostly by households (42.1% of total gas consumption in 2000) and the rest goes for further transformation (European Communities, 2003b).

Solid fuels, including coal, lignite, peat and oil shale, constitute 14.8% (215 Mtoe) (European Communities, 2003b). In absolute terms, 80% of fossil fuels reserves in Europe are solid fuels (72 billion tce), 70% of which is hard coal. They are attractive options because Europeans resources are plentiful and the rate of their use is much lower than oil and gas. However, the quality of this fuel varies significantly and production cost is high due to high extraction cost from deep mining and high labour cost, while being less efficient compared to other energy sources. Coal mining in EU is located in Germany (60 Mtoe), the UK (18 Mtoe), France, Spain (8 Mtoe), Belgium (8 Mtoe) (European Communities, 2003b), and is subsidised; trend for increasing share of imported cheap coal is observed, making EU more dependened on foreign supply. Coal is imported mainly from Australia, Canada and USA with average price 42 €/tce over 1995-1999 (compare to 143 €/tce for German coal). A great advantage of coal is its worldwide abundance, excess of supply over demand, leading to relatively stable prices over time, and thus it becomes an attractive option in terms of security of energy supply (European Commission, 2001b).

During long period of time coal was main fuel for conventional thermal electricity plant, representing 72.3% of market for solid fuel. During recent years electricity production shows considerable switching to natural gas as preferred fuel input. Between 1990 and 2000 share of solid fuel in conventional thermal power plants dropped from 67.6 to 52.2% (European Communities, 2003b). Additional reason for losing interest in coal is harmful emissions released during its combustion. Coal has been eliminated from home application due to air pollution reason. Despite of development of clean technologies of coal combustion and introduced measures to cut down emissions, it is still a big air polluter, including CO_2 emissions. But in the nearest future coal may gain importance again for power generation industry as prices for gas are projected to go up due to growing demand, and decommission of aged nuclear reactors will decrease amount of electricity generated by them (European Communities, 2003b).

22.9% of solid fuels in 2000 was accounted for as inputs into patent fuel and briquetting plants, coke-ovens or blast furnaces. Taking into account all transformation inputs, outputs, losses and own consumption within the energy branch, only 38 Mtoe of 215 Mtoe of solid fuels became available for final energy consumption in the EU in 2000 (European Communities, 2003b). Most of this total was used by energy-intensive industries, mainly iron and steel (60.4 % of final energy consumption in 2000). Households accounted for 10.9 % of final energy consumption of solid fuels, which is 14% less than in 1990 (European Communities, 2003b).

More than half (56.1% in 2000) of electricity in EU is generated on thermal power plants that means burning of coal, fuel oil and gas, though some amount of bioelectricity is also produced. The largest share of electricity from fossil fuels (90%) is generated in Denmark, Greece, Ireland and the Netherlands. The most "green" electricity production is located in Luxemburg, Austria and Sweden and originats and from hydro-energy plants (European Communities, 2003b).

Sectors of economy, responsible for GHGs emission are presented on Figure 2-2.

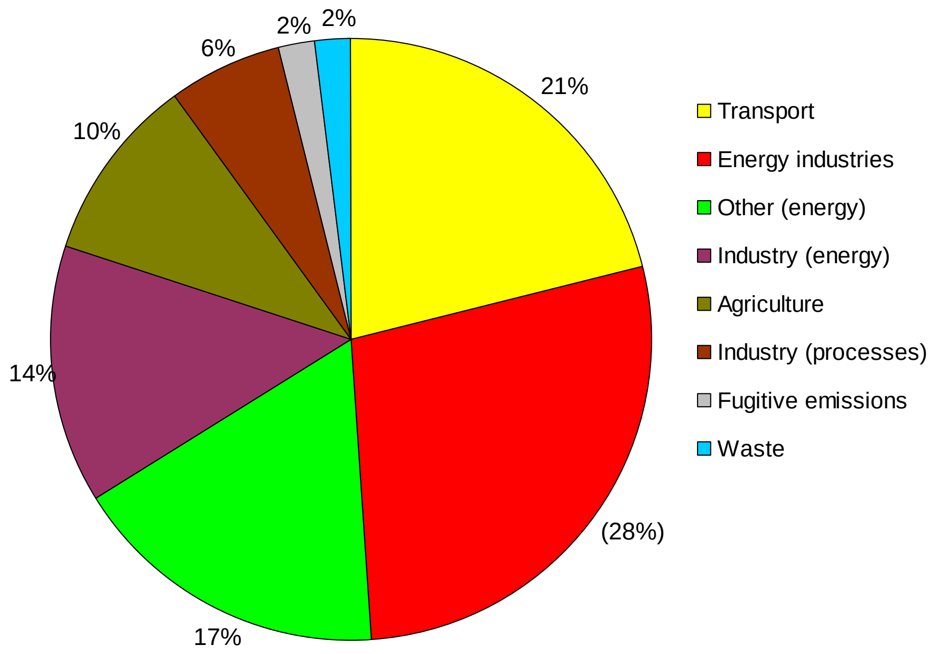

Figure 2. EU-15 GHGs emissions in different sectors in 2001. (Source: European Environmental Agency, 2004).

The most contributing branches are energy industry (electricity generation and refinery), industry (fossil fuel combustion and processes) and transport. Some progress in carbon emission reduction in energy sector has been observed in recent years. The largest reduction of CO_2 emissions were achieved in manufacturing industry by 8% or 55 million tonne mainly due to economic restructuring, efficiency improvement and switching to other fuels, and in energy sector (heat and electricity production) by 5% due to substitution of coal by gas and efficiency improvement. Additional contributing factor for GHGs reduction in energy sector was an expansion of wind electricity generation in Denmark, Germany and Spain. Wider implementation of solar, thermal energy and biomass district heating allowed significant reduction of CO_2 emissions in small combustion sector (EEA, 2004).

Unlike other sectors, transport, which includes road transportation, civil aviation, railways, navigation and other transportation, increased CO_2 emissions by 18% or 128 million tonne between 1990 and 2000 mainly through fossil fuel combustion. The largest contributor to transport emissions is road transportation – 84% in 1999. Transport volumes by road measured in passenger-kilometres or ton-kilometres are the driving forces of CO_2 emissions from transport. Passenger and freighted transport increased by 17 and 42% respectively between 1990 and 1999. Growth in amount of emission was strongly caused by growing demand for transport, mainly road, which was driven by economic growth (EEA, 2004).

At the present time the energy sector as a whole is responsible for 94% the man-made CO_2 emissions in Europe. Of this amount 50% comes from oil consumption, 22% is allocated to gas and 28% to coal combustion. The most contributing electricity and heat production sector has the greatest potential for growth in CO_2 emissions in the future because of growing energy demand and consumption, if no measures, technical or policy, are taken (European Commission, 2001a). According to some calculations, with current trend in growing in energy demand and burning fossil fuels in particular, CO_2 level in atmosphere will increase from current 360 ppm to 550-600 ppm in 2050 leading to catastrophic climate change. This threat, together with a number of other factors, could be the reason dampening further exploitation of reserves (European Commission, 2001b).

In summary, factors that have impact on CO_2 emissions are: population, GDP per capita, energy intensity of GDP, the share of fossil fuel in energy consumption and the shift among fossil fuels towards fuel releasing less carbon (EEA, 2004).

The European countries are extremely dependent on its external fuel supply. Import constitutes around 50% of energy requirement and will rise to 70% in 2030 with current trend that means even greater dependence on gas and oil. Elaborating long-term strategy pursuing security of energy supply, priority has to be given to global warming combating. Development of renewable energy sources, particularly biomass fuels plays fundamental role in this battle (Commission of the European Communities COM(2002) 321 final).

2.2 Biomass utilisation

Biomass energy, together with wind, photovoltaic (PV), solar thermal and hydro energy, belongs to major renewable energy sources (RES). Currently RES have a modest role in European economy but have potential to play more significant role in energy mix positively influencing all kind of economy sectors. EU has set the objective to double energy supply from renewables from 6 to 12% and to raise their share in electricity generation from 14 to 22% until 2010. In 6.1% (89 Mtoe) of renewables more than half (3.7% or 53.9 Mtoe) accrues biomass (data for 2000) (European Communities, 2003b). In 2002 France occupied European leading positions in wood energy sector with respect to amount of "green" tonne of oil equivalent produced. Germany had the highest growth rate of primary energy generation of wood origin. Sweden and Finland are countries with vast wood resources and belong to the leaders of wood energy production. Several European countries have programmes for development of their wood energy sectors. "The Wood Energy Plan" in France can facilitate keeping the country in leading positions in this sector. Denmark is going to convert all its heat production facilities running on wood into co-generation plants. In spite of efforts of EU Member States in developing biomass energy they are not enough to fulfil EU target that was set at the level of 100 Mtoe by 2010. With current trend EU countries will be able to reach at max 71 Mtoe (EurObserv'ER, 2003), but even more pessimistic figure of 62 Mtoe was also forecasted. The growth rate of Bioenergy should be reinforced.

From an environmental point of view, biomass is an attractive fuel because its net life cycle GHGs emission, not balanced by natural processes, constitutes 20-60% of those of fossil fuels. Currently the typical power capacity of commercial unit running on biomass is 10-30 MW. New technologies, like biomass integrated gasification combine cycle, are capable of significantly increase conversion efficiency of biomass to electricity with total combined (heat + electricity) efficiency 80%. At present, installation cost of biomass combustion plant is around 1500 €/kW with some variations depending on technology used and scale of plant that is slightly higher compared to wind mills, though production cost is on the same level as for wind energy. Even though biomass energy development remained on almost the same level since 1990, with further investment in technology, development biomass is predicted by experts from European Commission to gain more attention and market will grow. A significant part of biofuel is expected by experts from European Commission to come from agriculture. Provided that 20 million ha of arable land for dedicated energy crop cultivation with yield 6 toe of biomass per hectare plus 150 Mtoe of waste biomass are available, biomass has theoretical potential to expand even more, covering up to 20% of primary energy sources (European Commission (2001b).

Biomass has the highest potential to disseminate to decentralised power plants, especially CHP, and for substitution of fossil fuel in electricity generation. High efficiency of biomass firing power plants is made possible by simultaneous heat and electricity generation. It is important for northern European countries, where low value lost heat is recovered and demanded for district heating. In case heat is not needed, power plant can be used only for electricity generation, its efficiency drops from as high as 85 to around 40% (Mats Malmberg, IIIEE IO Mgt Course lecture, November 10, 2003). Main competitors of biomass in electricity production are wind energy and photovoltaic. Advantage of wind mills are their lower, compared to biomass CHP plants, installation cost (1000 €/kW). Due to new technologies for off-shore installations, improved construction and new generation of variable speed generators, wind energy is experiencing dramatic growth with potential to satisfy up to 30% of EU needs in electricity. PV is currently in a very small scale mainly because of very high installation cost (5,000 €/kW). In sunny Southern Europe production cost is 5 times higher compared to wind electricity and constitutes 0.32 €/kWh. PV systems can get relatively small share in EU electricity generation and most probably will be decentralised, being integrated into buildings and other multipurpose installations, especially in cities, where space is limited (European Commission (2001b).

European Wind Energy Association (2004) gives costs of wind electricity of the order 6-8 c€/kWh for the low average wind speed and 4-5 c€/kWh for the best wind farm location. Costs of photovoltaic power are calculated by IEA (2003) at least 17 c€/kWh and the figure for biomass electricity is 7 c€/kWh. However, these cost may be reduced to 5-6 c€/kWh for CHP plants or even to 2-4 c€/kWh for co-firing with fossil fuel due to avoidance of investment costs on the power cycle.

Part of biomass in 2002 was converted into liquid fuels and was put into vehicles' tanks instead of petrol, though this constituted less than 1%, but share of biofuel is growing. Biofuel sector has two distinct sectors:

- ethanol, which can be used directly as vehicle fuel, blended with conventional fuel or transformed into ethyltertio-butyl-ether (ETBE) and used as additive to petrol in Otto engine cars;

- biodiesel, which also can be used directly in diesel engines or used as additive to fossil diesel (EurObserv'ER, 2003).

Biofuel sector grow by 38% in 2002, increasing total volume from 1 069 700 to 1 493 200 tonne (Appendix 1) (EurObserv'ER, 2003). Ethanol production grew by 46.9% since 2001 (EurObserv'ER, 2003). Spain increased its ethanol production two times compared to 2001 by installing new production facilities, and now is leader in this field. Unlike other European producers, Sweden does not convert ethanol into ETBE but use it directly as a fuel. Biodiesel production went up by 37% compared to 2001(EurObserv'ER, 2003). Germany has the larger biodiesel production capacity – 670 000 tons/year, and five biodiesel production plants are under construction with total capacity 270 000 tons/year. This will make Germany the largest biodiesel producer not only in Europe, but also in the world (European Bioenergy Networks, 2003b).

With current trends for liquid biofuel production, EU countries are projected to reach the level of 11.7 million tonne by 2010, EU requirement regarding biofuel consumption is 5.75% or 17 million tons. With promotion of EU Directives that set targets for the share of biofuel in fuel blend and introduces tax incentives, biofuel sector can develop this renewable energy sector more (EurObserv'ER, 2003).

2.3 Future projections of energy resources (fuel mix)

Energy development is presented in a business-as-usual projection. Concept "business-as-usual" means movement forward with past trends in energy supply and consumption, behaviour and technology development. In practice, future energy will differ from "business-as-usual" because governments most likely will adopt and introduce policies in order to deliberately change business-as-usual practice and to meet commitments taken under Kyoto Protocol to reduce GHGs emissions by 2008-2012.

With current energy policies, there are several uncertainties regarding future energy consumption, supply and prices:

- economical and technological factors that condition energy demand;
- supply technologies;
- fossil fuel resources (Bourdaire, 1999, 29).

The choice and cost of future energy systems will be shaped by technological development. Technological development probably will focus on technologies with low or zero carbon emission and will be strongly influenced by governmental policies in taxation and prices as well as funding of R&D programmes.

Economic growth and energy use go parallel over history. Higher levels of industrial development and economical activity in total were followed by escalation in energy consumption, and visa versa (Bourdaire, 1999, 31-33). This trend is likely to continue in the future in all three sectors where fuels are used: for heat, electricity generation and production of fuel for transport. New policies will be required to decouple this relationship in the future (for example, Commission Proposal COM(2003) 739 final).

Perspectives of oil supply will be affected by market development, policy and technological changes. Amount of long-term oil supply is restricted by cost of recovering of conventional and unconventional oil. The size of world's ultimate oil reserves are uncertain and are estimated by United States Geological Survey from 2.1 to 2.8 trillion barrels with most likely figure 2.3 trillion, International Energy Agency projects 3 trillion barrels (Bourdaire, 1999, 33-34), though British Petroleum gives figure 1.15 trillion barrels of known and proved reserves and projects them to last around 41 years (British Petroleum, 15 June 2004) with current consumption level around 75-76 Mbbl per day (British Petroleum, 2003). Ultimately recoverable resources have grown constantly and are expected to grow in the future with improvement of oil development techniques (Bourdaire, 1999, 34).

Oil production reaches its peak when approximately half of ultimately oil reserves are recovered. Time when it happens depends on estimated oil reserves, technological advances and future oil prices. International Energy Agency calculated that peak production will take place in 2016 with assumption of 2% annual growth rate and then 2% decline rate (IEA, 2001). Oil supply from Middle East, major European oil supplier, can reach peak point even earlier, in 2015 since conventional oil supply will not be able to cover growing demand. Non-conventional oil sources, like heavy oils and tar sands, may become important and more economically viable to exploit (IEA, 2001).

Estimations of conventional natural gas reserves did not show any expected constrains well beyond 2020 (Bourdaire, 1999, 36). However, the marginal cost of supply will increase drastically, especially when gas resources, close to the market, have run out. Any potential supply shortage in gas market would stimulate prices to go up, that in turn will stimulate gas suppliers to develop additional sources: non-conventional gas resources, that have huge potential (coal-bed methane, deep offshore, tight gas, arctic resources, though their development costs could be high, but it will depend on successful research and development); coal gasification; import of liquefied natural gas (LNG). LNG becomes more attractive alternative to conventional gas supply, its production is growing due to technological progress and thus downward trend in supply costs is observed. This option could bring gas into Europe from long distance sources currently too costly to transport from. It would ensure security of gas supplies in the future. Economical viability of gas transportation in liquefied form starts from the distance 4000 – 6000 km, below which pipelines are cheaper (European Commission, 2001b).

From energy security point of view, coal has major advantage since its resources are widely distributed around the globe. With current extraction level (around 2100-2400 Mtoe, according to British Petroleum, 2003), the world's proven coal reserves, which are economically and technologically feasible to recover, could last at least 200 years (IEA, 2001). There is less uncertainty for future coal production compared to oil and gas. Production cost goes down with technologies development that adds extra point to coal over other fossil fuels. But due to increasingly stringent environmental standards, natural gas is preferable input fuel for power stations. The use of solid fuel in Europe is expected to go down both in absolute figures and as share in fuel mix. Coal can gain more importance after 2015 when a lot of nuclear plants will be decommissioned and gas based power will become more expensive due to increased gas import prices (European Commission, 1999). Long-term perspectives of coal using in this sector mostly depend on development of combustion technologies that reduce SOx, NOx, particulates and carbon emissions. During coal combustion twice as much CO_2 is generated per kWh is released compared to gas. Clean Coal Technologies (CCT) will play crucial role. In competition for lower carbon emission coal in current generation of CCT is well behind. The most promising CCT is Integrated Gasification Combined Cycle (IGCC) power generation that also produces much lower SOx, NOx and particulates emissions. This technology is under development in Europe as well as in the US and Japan. Thermal efficiency of IGCC may reach 50%, which is higher than of conventional plants (33-40%) (IEA, 2001).

Renewable primary energy resources will play increasingly significant role in energy supply. They are expected to significantly disseminate into electricity generation, demand for which is going to increase. Technological innovation and government policies, especially related to CO_2 emissions, can become crucial factors, promoting and speeding integration of renewables into power sector. Renewables in EU are going to continue to be encouraged and promoted by European Commission to reduce GHGs emissions and enhance security of energy supply in particular on the background of noticeable declining domestic oil. In the presence of substantial penalties for carbon emission, renewables will become an option for power generation up to 2020 even in spite of their higher cost than for fossil fuel. Amount of cost reduction and time when they can provide realistic competition to fossil fuels are highly uncertain. Up to 2020 supply of renewables are expected to be concentrated in industrialised countries.

With regard to biomass, increased productivity of energy crops will provide conditions for bioenergy production. Though availability of land, water and competition for other uses (mainly for food) will condition long-term production capacity of energy crops, advanced biomass combustion technologies, like gasification and pyrolysis, can push the use of biomass for heat and electricity generation. Biomass can be processed into liquid biofuel for transport provided that production cost falls radically. Cheap feedstock can also facilitate this process. Biomass can be cheap raw material for hydrogen production with its further utilisation to power fuel-cells when fuel-cell technologies will become cost-effective. Pyrolysis and gasification of biomass generate fuel gas, which is used for hydrogen production. In this case hydrogen-based fuel-cell system will be much more "green" in terms of related CO_2 emissions compared to other fuel input (IEA, 2001).

Facing carbon constrains, the economic system can decrease carbon intensity by shifting from one fuel to another, containing less carbon, and by reducing its energy intensity. In the nearest future by 2010 almost half of emission reduction will be achieved by means of the latter option. By 2020 this effect declines and changes in fuel mix, substitution of some fuels will be required to achieve further progress in GHGs reduction (European Commission, 1999).

2.4 Conclusion to Chapter 2

European's economy is highly dependent on fossil energy resources that has consequences in the form of economic instability of energy-related branches of industry as the most of fossil fuels are imported, as well as negative environmental impact due to high level of CO_2 emissions. Moreover, import is growing over time. In spite of some reductions of CO_2 emissions achieved in energy sector, energy generation is still the most polluting industry in Europe. One of the possible solutions to improve situations in both named directions and to contribute to achievement of other goals of EU Energy Policy (improvement of local environmental conditions and creation of job opportunities, especially in rural area) is wider use of renewables and biomass in particular for heat, electricity and automotive fuel production. The actual effect of biomass energy on these goals depends on a number of variables and is specific in different local conditions. The hindering factors for bioenergy economy are the high installation and production costs that can be overcome not only through organisational and management measures, but also by better crop selection, successful conversion technology development and supporting policy instruments.

3 Dedicated energy crops

Biomass for energy purposes is a very broad term and includes all forms of organic material such as wood, herbaceous plant matter, agricultural crops, agricultural residues, aquatic vegetation, animal manure, and municipal solid waste. On conversion stage, biomass can be converted into heat, power or fuel by means of thermochemical (direct combustion, distillation, pyrolysis) or biochemical (fermentation, anaerobic digestion) processes. Hence, there are number of conversion pathways, and together with range of feedstock it infers a variety of environmental issues related to a particular system.

Among the varieties of biomass, attention will be paid to dedicated energy crops for a number of reasons. Amount of biomass from energy crops is more or less predictable and could be available in sufficient quantity, as opposed to residues, and the increase of this quantity is desirable. A number of plants are suitable for cultivation for energy purposes:

- Fast growing hardwood trees, such as willow, poplar and eucalyptus. Trees may be grown on a short rotation basis, which allows harvesting every 2 to 6 years (depending on the species) for a period of 20 to 30 years. Trees are planted very densely, and then allowed growing for one year before being cut back almost to ground level to increase the number of shoots which may be subsequently harvested every few years.

- Annual and perennial grasses such as fibre sorghum, miscanthus, and cynara. Annual grasses must be re-sown each year, while perennial grasses may be harvested annually for several years before replanting is necessary.

A comprehensive list of plants suitable for growing as energy crops can be seen in Appendix 2. The choice of a crop species for a particular location depends on factors such as geographical and climatic conditions, amount of rainfall or other water supply, annual temperature profile, and soil condition and nutrients. Land, machinery, plant material, fertilisers and crop protection agents for the maintenance of the crops are required for cultivation of crops. Italian study (Venturi and Venturi, 2003) gives the broader list of requirements for crops to be successfully introduced for energy purposes:

"(a) suitability to certain pedo-climatic[1] conditions;

(b) ease of introduction in pre-existing agricultural rotations;

(c) uniform and continuous yield levels with respect to amount and quality;

(d) competitive income compared to traditional crops;

(e) a positive energy balance with respect to ratio (output/input[2]) and especially net gain (output − input);

(f) growing techniques in harmony with the concept of sustainable agriculture;

[1] The world "pedo" concerns the soil that really influences the growth of the plants (organic matter content, different elements, texture, etc.) so, the word "pedo-climatic" include soil and weather conditions.

[2] Energy ratio is the ratio of amount of energy obtained to the total amount of energy input.

(g) resistance to major biotic and abiotic adversities;

(h) availability of genetic sources (seeds, rhizomes) suited to different areas;

(i) proper machinery (mainly for harvesting operations) suited to the crop or usable with slight changes."

Because of competition for land, which can be used for wide range of goals, yield is probably the main parameter that justifies the use of land for growing of energy crops. Yield can vary substantially depending on there was extensive production system (with minimal inputs) or intensive one (with large inputs). In the former case, yield is usually lower. Inputs include indirect energy, required for production of artificial fertilisers and pesticides, as well as direct energy for their application. These figures, expressed in GJ per ha or per unit of product, are higher for intensive agricultural practice. The highest amount of biomass, related to unit of energy (and fossil energy) input, is obtained in low-input crop production, that means that with decreasing energy, input by a certain percentage crop yield drops more slowly (Nonhebel, 2002).

Aiming environmental, social and economic sustainability of energy crops, several models with different methodologies were proposed, though they are rather complex and difficult to gather necessary data. A simpler approach allows using and analyse available data regarding input and output, transforming them into ratio (output/input) and energy gain (output – input). Energy gain is important factor, because with high ratio output/input actual yield can be so small, that it does not represent any commercial interest. "Instead the gain furnishes an idea of the energy potential developed under different pedo-climatic conditions, organized depending on the growing techniques used." However, this approach does not consider differences in agricultural practices as well as uniqueness of each individual energy source, which possess different sets of characteristics, thus omitting some relevant information (Venturi and Venturi, 2003).

The same agricultural crop can be used either as food or for energy purpose (e.g. rape seed, wheat, barley, sugar beet, and so forth). Unlike food production, where the value of harvested crop is not measured by its heating capacity and thus interest to efficiency of energy use is limited, in the case of crops for energy purposes, energy yield and fossil fuel use efficiency are key parameters that determine potential for growing. Only crops, for which energy output significantly overweighs energy input, can be considered as energy crops and present an interest to growing. The importance of the energy ratio parameters with respect to energy crops justifies further investigation (Nonhebel, 2002).

In some cases crops traditionally used for other than energy purposes, are currently adapted for energy production. Well known examples are *rapeseed* and *sunflower* oil for biodiesel production, *cereals* for fermentation into ethanol. "Newcomers" to energy crops are *eucalyptus*, mainly grown in Portugal for pulp production; *hemp* and *kenaf* are mainly cultivated for fibre.

Energy crops influence local, regional and global environment (Hanegraaf, Biewinga, and van der Bijl, 1998). From this point of view, their environmental end economical sustainability is a very important factor. This chapter presents information on primary production of energy crops in EU countries. It covers agricultural, technical, environmental, energy and economical aspects.

3.1 Woody crops

3.1.1 Willow

Willow is a highly developed energy crop and is grown mainly in Northern Europe. High priority for willow production was given in Sweden since 1975 and became on commercial scale since 1991. Approximately 17 000 ha of willow are established. Estimated net yield in Sweden is 8-10 odt/ha/yr (odt – oven dry tons[3]) but 12 odt/ha/yr is achievable provided obtaining of full benefits from improved genetic materials and optimising of agricultural practices. Willow production in Sweden is subsidised (Venendaal, Jørgensen, Foster, 1997). Production cost varies from country to country in the range 38 – 86 €/odt and in average constitutes 59 €/odt, which drops to 50 €/odt with subsidies for plantation establishment.

In the UK short rotation crops, to which willow belongs, are considered as the most promising energy dedicated crops. Area of land for willow growing before 1997 was insignificant and constituted 200 ha but was planned to increase to 2000 ha in the near future. Average yield is obtained on the level of 10 odt/ha/yr under commercial cultivation with variations from 8 to 20 odt/ha/yr. Among available salix species and clones, only disease resistant ones were recommended, from which farmer could make a choice based on specific soil conditions. The most affecting disease is willow rust, so clonal mix is advised to decrease the possibility of its occurrence. Willow is considered as an environmentally friendly species since only a few herbicide treatments and no insecticides and fungicides are required during the whole life cycle of the crop. It creates low emission into water, has good carbon balance and could be a habitat for fauna and some species of flora. In addition, the crop can be used as a vegetation filter for wastewater and for safe sludge disposal. However, willow is water-demanding plant, thus availability of water is crucial factor for willow growing. Return of ashes is considered as important step of salix use to put nutrients back to the soil (Venendaal, et al., 1997).

In Finland, in spite of big desire, salix cultivation was not successful due to number of reasons. Peatlands, where willow was planned to be planted, are too acidic; additionally, severe frosts damage most of salix plantations. So, in total only 20 ha has been established so far (Venendaal, et al., 1997).

In Denmark willow is planted on the area of 400 ha with average yield 7-8 odt/ha/yr. In Ireland, where climate is considered as optimal for willow production, achieved yield was only 5 odt/ha/yr. No commercial willow production, only 100 ha of willow plantations is established. In the Netherlands willow is grown on the area of 1800 ha for non energy use. Some researches conducted in Italy, showed annual yield 15-20 odt/ha (Venendaal, et al., 1997).

Willow is not a traditional agricultural crop and hence its introduction to agricultural practice is a long process. Even if its production technology is well developed, further increase of cultivation area is constrained by farmers' perception of this crop. Among recognised barriers are long crop rotation (20 years), lack of long term legislation and risk of increased pest problems. The investment risk and production economy could be improved by low-cost establishment that would also ease for farmers start new business. Swedish experience showed

[3] Oven dry - wood dried to constant weight in a ventilated oven at a temperature above the boiling point of water, generally 103 ± 2 Celsius degrees. Source: http://www.websters-online-dictionary.org/

that it is difficult to introduce new technical development because of farmers' opposition (Venendaal, et al., 1997).

3.1.2 Poplar

Poplar is more heat-loving crop than willow, but both species are cultivated in the UK, Germany, Austria, Ireland and Belgium. Plant density varies from 700 to 1700 trees/ha and is harvested typically every 4-6 years. Mean yield is 10-15 odt/ha/year with variations of annual production from 3 to 30 odt/ha. Establishment of poplar plantation costs about 1600 €/ha. This high cost is a barrier for further establishment of poplar plantations, as well as availability of water (Venendaal, et al., 1997).

In the Netherlands, poplar has been grown during 50 years and now is established on the area of about 32 000 ha, but not for energy purposes, though several research projects started to investigate this unused potential. The same hybrids as in the Netherlands are cultivated in the UK. In Italy, poplar is grown only on small irrigated research plots with annual yield 15-20 odt/ha. In France, poplar is grown on the area of 350 ha, annual yield under commercial practice is in the range 6-12 odt/ha, and is used for pulp production. In Austria, poplar and willow are cultivated on the area of 840 ha, average yield is 2-12 odt/ha/year (Venendaal, et al., 1997).

As it can be seen, poplar is grown on big area, but not for energy purposes, though it seems to be more pest and diseases resistant compared to willow. In general information about poplar is rather limited and is not related as for energy source. Any information transfers on this regard between countries would be very valuable (Venendaal, et al., 1997).

3.1.3 Eucalypt

Portugal possess the largest plantation of eucalypt in Europe, accounting approximately 500 000 ha for pulp production. The eucalypt that is used for pulp and paper is very frost sensitive species and cannot be grown northern in Europe. Eucalypt is usually harvested every 8-10 years and potential yield provided irrigation and fertilisation could exceed 20 odt/ha/year, however it very much depends on soil conditions and varies from year to year (Venendaal, et al., 1997).

First eucalypt plantation in France were established in 1972, however they all were destroyed by frosts during very cold winters of 1983-85. Now the most researches are focused on breading of frost resistant species for energy production. Currently eucalypt for pulp production is grown on the area 507 ha under commercial conditions with estimated yield 8-14 odt/ha/year. In Greece and Italy eucalypt is cultivated only on several hectares of research plots since 1990s. On fertile soil annual yield achieved was more than 20 odt/ha that drops to 6 odt/ha on less fertile fields. Estimated production cost in France is 46 €/odt (Venendaal, et al., 1997).

Experience of eucalypt growing for pulp production is vast and can be easily transferred to the one for energy purpose. Production cost is 46 €/odt that makes eucalypt a better option among energy woody crops, provided that eucalypt cultivation without irrigation continues to be successful.

3.2 Herbaceous crops

An ideal energy crop should allow having high energy output with low input, being environmentally and commercially viable while requiring low investment and being cost-effective (Heaton et al., 2004).

3.2.1 Miscanthus

Perennial rhizomatous grasses[4], especially using C_4 photosynthetic pathway[5], are typically capable using solar energy, water and nutrients more efficiently compared to other plants. Nutrients are seasonally cycling in the plant up and down. Harvesting of a senescent crop has several advantages:

- nutrients relocate to the root system, facilitating their not removal from soil and minimising additional introduction of fertilisers;

- overground part of plant has low level of minerals, thus little air pollution will be released during combustion;

- perennial crops require only one planting, preventing soil from every-year tillage, bound fossil fuel consumption and erosion (Heaton et al., 2004).

Perennial crops, being mature when harvested, can provide higher amount of clean dry fuel per unit of energy input compared to other potential energy crops. C_4 photosynthesis pathway is up to 40% more efficient than C_3 pathway and allows crops to capture and store solar energy more efficiently, meaning that they use the majority of available sun light and have higher conversion rate of solar energy into biomass, that is especially important in colder environment like in Northern Europe (Heaton et al., 2004).

Miscanthus is a typical C4 perennial plant, known in Europe for last 50 years. It likes warmer climate. Area, where miscanthus can be grown, is restricted from the north by Denmark, southern Sweden, the UK and Ireland. Denmark was the first European country that started cultivation of miscanthus in 1960s for pulp and energy production. Average yield was 7-14 odt/ha in the spring harvest. Since this is only half of what is biologically produced by plant, because leaves and tops are lost during winter (30% of biomass), it was decided to harvest miscanthus in autumn. Several drawbacks of autumn harvest like higher water and mineral content of plant were expected to be overweighed by lower production cost due to reduced storage cost as harvested material would be delivered directly to heating plant. Establishment cost is prohibitively high to make miscanthus competitive energy crop as it has been revealed by German's research programme (2500 – 5000 €/ha). This sum divided on total crop lifetime constituted 50-60% of annual production cost. Low-cost (1000 €/ha) method indicated faster crop establishment and better survival of plants during winter. Experiments, conducted on research plots in Germany, showed that crop establishment is influenced by soil type and goes faster on sandy soil, while clay soil provides higher yield (Venendaal, et al., 1997). Miscanthus is seeded by rhizomes. With cost 0.04 $US per rhizome and seeding rate 10 000 plants/ha cost of material constitutes 402 $US/ha (Heaton et al., 2004).

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[4] Plants, producing or possessing rhizomes - horizontal plant stems with shoots above and roots below serving as a reproductive structure.

[5] C_3 and C_4 are photochemical mechanisms used by plants to capture CO_2 from atmosphere. For details see: http://www.ehleringer.net/Biology_5460/Lectures/A_quick_review_of_C4.pdf

General picture of miscanthus growing in Europe indicates low yield (4 odt/ha) in the first year and annual yield around 10 odt/ha in the following years from the field under commercial exploitation and up to 15 - 20 odt/ha on research plots with better soil and irrigation in Northern European countries like the Netherlands, Denmark, the UK, Austria. For Southern Europe mature crop can produce about 20 odt/ha on commercial fields and up to 30 odt/ha on research plots yield (Venendaal, et al., 1997). More up-to date study (Heaton et al., 2004) gives figures of average yield 22.4±4.1 ton/ha of mature crop (3 years and older) in autumn harvest (1 September).

Miscanthus is considered as environmentally friendly crop with exception of the first year, when ground is sparsely covered with plants and weed treatment is highly recommended. Any severe pests hit miscanthus plantations so far. Main barriers for further miscanthus development were identified as low survival during the first winter, especially in Northern Europe, and high establishment cost, which is higher that for other perennial crops. Researches are conducted in both directions. Winter survival can be improved by breeding and selection, aiming genotype change. It can both make crop better adapted to cool climate and decreases risk of occurring future problems with pest, reduce mineral content of the harvest. National reports provide figures of establishment cost from 32 to 977 €/ha. The lowest figures were calculated in Denmark and the Netherlands with anticipation of new low-cost methods, which cut down establishment cost to the level lower than for willow and annual crops. Low cost could be reached through changing the way crop is planted and reducing amount of fertilisers and pesticides since miscanthus tolerates low input of them. Cost of each odt, delivered 50 km to a heating plant, ranges from 34 to 73 € depending on establishment cost and anticipated yield. Thus, countries with low-cost establishment practice and high yield would be more profitable and cultivation of miscanthus for energy purposes would become economically viable (Venendaal, et al., 1997).

Miscanthus has a great potential to be use as biomass energy crops. First of all because it can be harvested annually and has lower moisture content when harvested compared to short rotation coppices.

3.2.2 Reed canary grass (RCG)

Sweden, where like in other Nordic countries RCG is native crop, has large experience in its cultivation for energy purposes. Initially it was grown for fodder. Due to grants for converting from food crops into non-food crops in Sweden several thousand hectares of RCG were established, of which only small share of grass was used actually for energy because the underdeveloped market for grass combustion (Venendaal, et al., 1997).

After the first year, when production is limited, annual yield of RCG under commercial conditions reaches 6-8 odt/ha. It is better to harvest in spring, when grass has low water content (it makes grass easier to store) and minerals transferred to the root during winter, reducing requirement of fertilisers and facilitating lower mineral emission when combusted. Under EU project on RCG research plots have been established in Sweden, Finland, Ireland, Germany, the UK and Denmark, aiming to further investigate influence of genotype and harvest time to increase yield and reduce mineral content (Venendaal, et al., 1997).

Compared to other perennial crops that have higher yield like willow or miscanthus, RCG has low establishment cost and it makes the crop very attractive for energy purposes. Weed treatment is required only during first year of plantation establishment that makes the crop very competitive. Serious pest invasions in RCG plantations have not been observed in Sweden so far. The crop tolerated flooding and droughts during several weeks. There is no special requirement for machinery, it does not take too much effort to turn from RCG cultivation to food production that is performed by conventional tillage operation. Aesthetical advantage of RCG is that, on the contrary to willow and miscanthus, it keeps the landscape open, reaching max 2 m in autumn (Venendaal, et al., 1997).

Production cost of RCG constitutes 66 €/odt in Sweden and 59 €/odt in Finland that is a little higher than for willow because RCG usually has lower yield is normally harvested in spring and should be stored until autumn, and salix is harvested in autumn and delivered directly to combustion plant. However, storage ability of RCG is good that guarantees security of fuel delivery (Venendaal, et al., 1997).

3.2.3 Cynara

Cynara is a perennial crop, growing in the dry climate of Mediterranean region in Greece, Spain, Portugal and Italy. Previously it was an edible crop, which later has been used for other applications like for energy and pulp and paper production. As an energy crop, its lifespan in central Spain is more than 10 years (Curt, Sanchez, Fernandez, 2002). In summer time no irrigation is required (unlike, for instance, miscanthus) since the plant uses water collected during winter rains. 450 mm rainfall is well enough to produce up to 20 odt/ha. Harvest takes place in the late summer, when it is dry (moisture content 10-15%), and consists mostly of capitula (45%) as well as leaves (33%) and stems (22%). Seeds (0.4-0.9 t/ha), which contain about 26% of oil, can be used for oil extraction (Venendaal, et al., 1997, Curt, et al., 2002).

Establishment cost is low, that makes the crop an attractive option for energy, though weed treatment is required during first year of establishment. Cynara is exposed to pests and fungi invasion, so in the following years appropriate treatment is recommended. This is one of the barriers that should be overcome by other than pesticides solutions, for example, by changing of agricultural practice or introduction of new pest-resistant genotype through breeding and selection, in order to make cynara more environmentally friendly (Venendaal, et al., 1997).

Cost of biomass from cynara constitutes 24 €/odt because of low establishment cost, low input of fertilisers, not needed irrigation and high yield that is very competitive price compared to other energy crops. Energy value of the crop per odt is higher due to oil content (Venendaal, et al., 1997). Other study (Curt, et al., 2002) indicates production cost 44 €/t of dry matter, or 2.98 €/GJ.

3.2.4 Hemp

Hemp has been traditionally grown as fibre crop and some researches have been made to use hemp as input for pulp production. A new idea is to use it for energy purpose. Hemp is similar to maize and in the case of the use for energy should be harvested completely, but optimal harvest time is not defined yet and further investigations are required. From experience, obtained in the Netherlands from hemp cultivation for pulp, the yield is 10-17 odt/ha with the best figures for clay soils. Herbicide treatment is not required since the crop can successfully compete with weeds for resources, but fungi can substantially harm the crop in wet years, however this could be solved by selection and breeding (Venendaal, et al., 1997).

From environmental point of view, hemp seems to be environmentally friendly since it requires low input of fertilisers and pesticides, has relatively high output. Standard machines could be used for sowing. The crop fits well into crop rotation. Production cost in the Netherlands is estimated as 84 €/odt, the significant share of which is storage and could be possibly reduced (Venendaal, et al., 1997). However, public perception of the crop should be taken into consideration before wider implementation of hemp in agriculture.

3.2.5 Comparative analysis of herbaceous energy plants

Yield range and energy balance for herbaceous energy crops is presented in Table 1.

Table 1. Energy requirement and output for herbaceous crop production in Europe.

Crops	Yield range					Energy balance	
	Fresh matter, t/ha	Dry matter		Energy content, GJ/t	Output, GJ/ha	Ratio output/input	Gain (output-input), GJ/ha
		%	t/ha				
Willow[a]		40	10-15	18.7	187-280		
Poplar[a]		55	10-15	17.3	173-259		
Fiber sorghum[b]	50-100	25-40	20-30	16.7-16.9	334-507	13-39	309-494
Sweet sorghum[b]	50-100	25-35	12-25	16.7-16.9	250-422	10-32	225-409
Hemp[b]	25-35	40-45	8-15	16.0-18.0	128-270	5-20	103-257
Miscanthus[b]	40-70	35-45	15-30	17.6-17.7	260-530	12-66	238-522
Cardoon[b]	25-35	40-45	10-15	15.5-16.8	155-252	7-31	133-244

Sources: a – McKendry (2002a), b - Venturi and Venturi (2003). Input range is 13-25 GJ/ha for annual crops and 8-22 GJ/ha for perennial ones.

The output of each species varies widely at first due to differences in environmental growing conditions, at second "because of the different genetic potential of the genotypes tested and the growing techniques used" (Venturi and Venturi, 2003). Energy balance (ratio output/input and energy gain) for all crops is highly positive. The highest energy potential could be observed for miscanthus, however, it is not cultivated on the farm level yet (Venturi and Venturi, 2003). So, further researches are necessary to put production of the most promising energy crops on commercial scale.

3.3 Oily crops

Rape and sunflower are considered as the most promising oily crops for further development. They can be grown on set-aside land all over Europe. Crops for biodiesel production do not represent any technical problems because they have been grown for food oil during very long period of time and production technique is well known.

3.3.1 Rape

Rape is European the most widely grown crop suitable for energy purposes. During a long period of time it was used for food and fodder. Erucic acid[6] free genetic modification of rape is grown for food production, though it is not necessary if crop is going to be used for energy. Rape seed oil has been relatively easily introduced into energy market. It is cultivated mainly in central-northern part of Europe over a wide area. The largest areas in EU under rape plantations in the whole for food and non-food production are located in France, Germany, the UK, Poland, Czech Republic (Venturi and Venturi, 2003).

A Swedish study (Mattsson, Cederberg, Blix, 2000), aiming comparison of land use by three oily crops (rape, soy and palm, which are important sources of oil in different parts of the

[6] Erucic acid is a fatty acid found in rapeseed, wallflower seed, and mustard seed, making up 40 to 50 % of their oil. Erucic has been shown to have a variety of health impacts. Source: http://www.websters-online-dictionary.org/

world) indicates, that among considered crops rape causes the least soil erosion – 0.03 – 0.05 tonne of erosion per ha per year (compare to 8 tonne for soy and 7-14 for palm). This fact is important since erosion is a serious threat to the soil that influences long-term sustainability of agricultural production and biomass supply in particular.

Production cost range from 140 to 250 €/odt of seeds. Machinery cost takes a large share in total production cost, so lower figure relates to cheaper machinery operations. In most cases production cost exceedes 200 €/odt, while if it constitutes more than 150 €/odt, production becomes not economically viable. So, rape seed production is heavily subsidised (Venendaal, et al., 1997).

3.3.2 Sunflower

As an oily crop, sunflower is an alternative to rape in central and southern Europe. It is grown in 23 European countries, 95% of which are located in 15 countries. Among EU countries the largest producers of sunflower oil are Spain, France, Hungary (Venturi and Venturi, 2003). Study (Venturi and Venturi, 2003) gives total figures of sunflower production, not taking into consideration the destiny of obtained oil (for food or non-food purpose). In Italy sunflower is commercially grown for biodiesel production on the area of 55 000 ha of total 227000 ha with average yield 1.7-2.4 odt/ha. In Austria of 39 000 ha of total area of sunflower only 1% was for non-food purpose in 1994. The plant is harvested in September, when the matter is dry and water content is around 10% (Venendaal, et al., 1997).

Low input required, ability to grow with limited water supply (sunflower can easily compete with other species with higher water consumption and evaporation rate), possibility to use conventional machinery for on-field operations belong to the advantages of sunflower. However, sunflower oil has a high iodine number[7], not suitable for methyl ester production that could be changed by breeding of low-iodine species (Venendaal, et al., 1997).

3.3.3 Comparison of rape and sunflower

Comparison of oily crops in terms of energy input/output is presented in Table 2. Around half of energy requirements for on-field operations for both species is fuel and about 25-35 % is nitrogen fertilisers application. The highest fuel consumption is observed on hilly areas. Energy production cost is higher with extensive agricultural practice. However, lower input does not mean automatically lower output. Low input could be implemented not only by reduction of resources use, but rationalisation of the use of tools. The use of high-capacity machinery can substantially reduce on-field operation time per ha, leading to reduction of fuel consumption. Rationalisation allows reduction of input for rape cultivation to 5 GJ/ha with maintaining the output on the level of 55 GJ/ha (Venturi and Venturi, 2003).

As it can be seen from Table 2, energy balance for oily crops appears not to be good, especially if by-products (meal) are not included in calculations, since oil content in the grains is less than half. That means that only tiny, if any, energy could be gained by producing oil for biodiesel. However, calculations in the table did not take into consideration possibility to use straw after harvesting as a solid fuel (Venturi, 14 July 2004). This would significantly improve total energy balance picture and make biodiesel production more viable from both energy and economic point of view. The other study (Venendaal, et al., 1997) displayed higher energy ratio for RME: 1.9-2.8 without straw utilisation. This figure is more commonly appears in

[7] Iodine number is a measure of the unsaturation of oils and fatty acids expressed in terms of the number of grams of iodine per 100 grams of sample, determined under specified conditions. Source: http://www.websters-online-dictionary.org/

publications and could be derived from higher crop yield and assumption of the lowest possible energy input. "We tried to reduce as much as possible the level of inputs in the production phase, this because we believe that this kind of energy crops must have a very small impact on the environment and 'on the wallet of the farmers'. Then there is not a clear correlation between production and input level. This could also explain why you never reach ratio higher than 1"[8] (Venturi, 14 July 2004). System boundaries also affect calculations.

Table 2. Energy requirement and output for rapeseed and sunflower oil production in Europe.

Parameter	Rapeseed	Sunflower
Output		
Grains yield range, t/ha	0.7 – 3.4	0.5 – 2.5
Oil content range, %	35 – 40	40 – 48
Oil yield range, t/ha	0.5 – 1.4	0.2 – 1.2
Energy content in oil, MJ/kg	37.4	38.4
Energy output range (oil), GJ/ha	**11.2 – 52.3**	**7.7 – 46.1**
Energy output range (meal), GJ/ha	**5.6 – 29.3**	**5.9 – 21.9**
Energy requirements for on-field operations		
Tillage, GJ/ha	3.5 – 14.4	6.3 – 12.5
Sowing, GJ/ha	0.5 – 1.4	1.2 – 3.2
Fertilisation, GJ/ha	5.6 – 13.8	8.1 – 13.8
Weed and pest control, GJ/ha	0.8 – 1.9	1.7 – 3.5
Harvesting, GJ/ha	2.6 – 5.5	2.7 – 5.0
Total, GJ/ha	**13.0 – 37.0**	**20.0 – 38.0**
Share of for on-field operations in total input, %	82 – 72	90 – 77
Post-harvest input, GJ/t	4.21	4.46
Energy balance for methyl ester		
Ratio output/input (with by-products)	1.0 – 1.5	0.4 – 1.2
Gain output-input (with by-products), GJ/ha	0.4 – 24.0	-11.1 – 8.1
Ratio output/input (without by-products)	0.7 – 1.0	0.3 – 0.9
Gain output-input (without by-products), GJ/ha	-4.7 – 1.0	-14.6 – -3.1

Source: (Venturi and Venturi, 2003). Data for output based on FAO data, average 1996-2000. Data for energy requirement are obtained from test in Italy.

Even though there are high requirements (estimated 500 000 t/year) for biodiesel and its public perception as a low-emission fuel, economic balance is not always positive and European countries are struggling to wider introduce it. In general, energy balance of oil chain is positive and two strategies could be considered to improve it even more:

- "extensive management with low input levels but, very often, causing insufficient output levels;

[8] The answer on the question why in a number of reports, available in Internet, figures of ratio energy output/input for both biodiesel and bioethanol are considerably higher than in the article published by authors. Moreover, this ratio is higher than 1 only if by-products are included in energy calculations.

- intensive management aimed at producing high yields with relevant inputs and costs" (Venturi and Venturi, 2003).

In the first case production will be constrained by low crop yield and the need of large area of arable land. Energy gain would be very low. In the second scenario oily crop production takes place on limited area and most likely will not fit into sustainable agricultural model (Venturi and Venturi, 2003). Ultimate truth, which combines moderate management system and relatively large cultivated areas, lies, probably, somewhere in between these two scenarios. It is important to supply enough input of raw material for the industry, while preserving soil quality and fertility for future generations.

3.4 Crops for fermentation

Oxygenated compounds, like ethanol, ETBE, are included into formula of gasoline to reduce emission of aromatic substances and olefins in fuels and, thus, in exhausted gases. Ethanol can be produced by transformation of cellulose materials (process is under development to make it cheaper and more economically viable) or by fermentation of crops with high sugar/starch content. In latter case, a lot of technologies exist. Carbohydrates can be stored in the seeds, stems or underground part of plants.

3.4.1 Sugar beet

Sugar beet cultivation has long history and is well established. Literature about sugar beet growing is widely known and easily available, that's why the agricultural details are not presented in the study. Growing of sugar beet for sugar extraction and ethanol production are not supposed to be different. There is no special breeding dedicated for ethanol manufacturing. Ethanol from sugar beet in France costs around half a Euro per litre (Venendaal, et al., 1997).

3.4.2 Cereals (wheat, barley, rye)

Cereals are traditional food crops and knowledge of their cultivation is vast and widespread. They can give high stable yields. Cereals can be used for combustion (straw) or for fermentation (grain). In some instances, grain is also can be combusted. In case of fermentation use, high yield of grain is important factor, while for combustion purposes total high yield should be obtained. An average total yields of 10-12 odt/ha, 5.5 odt/ha of which is grain, are reported from Germany and France (Venendaal, et al., 1997).

Mineral content of straw is an issue to pay attention to since it stipulates fertiliser removal during harvest and mineral emissions during combustion. Content of K and Cl depends on cereal species, type of fertilisers, soil type and amount of precipitation before harvest. Just the use of Cl-free fertiliser reduces Cl-content of straw on 50%, but even higher reduction is observed with just limited precipitation (Venendaal, et al., 1997).

Agricultural practice is mature and it would be easy to implement cereals as energy crops. "Environmentally friendly production systems can be adapted from food production and should be further developed since different quality criteria apply to energy grain." (Venendaal, et al., 1997). Cereals growing fits well into conventional crop rotation and, as annual crops, can be planted in the year when it is needed. However, with current market prices for biomass for energy, cereal production as energy crop is not profitable, production cost in Germany is estimated at 61-70 €/odt and a little more in Denmark and most likely will not decrease since cereal production is already optimised. Farmers may produce cereals on set-aside land at marginal costs provided available machinery and labour (Venendaal, et al., 1997).

Cereals are competitive compared to other energy crops for fermentation. The variety of agronomic techniques is available to choose among in order to reach the most favourable relationship between input and output. From agricultural and environmental point of view, the best cereals as energy source are wheat and barley. Wheat can be cultivated in any region and there is diversity of varieties giving high yield. Energy balance is positive for cereals.

3.4.3 Sorghum

Sorghum is of great interest in EU and has been studied in European projects. It is cultivated only on experimental fields, so all data about this crop comes from research spots and not from commercial fields. Interest in sorghum is due to its high efficiency of photosynthesis as a C_4 annual crop. Each MJ of captured solar energy the crop transforms into 2.42 – 3.30 g of biomass (for comparison, C_3 crops have roughly as much as twice lower conversion efficiency) (Venturi and Venturi, 2003). Both sweet and fibre sorghum could be used for energy purpose. Yield of sweet sorghum in Spain and Greece under irrigation constitutes up to 30 odt/ha, one third of which is sugar. High yield has also been measured in Italy and Portugal on small plots with irrigation. Fibre sorghum gives yield 6-15 odt/ha on the north of France and 8-20 odt/ha on the south. Some irrigation is reported as also needed. The same dependence of the yield on local temperature is observed in Belgium: 5-8 odt/ha in colder areas and 12-15 odt/ha in the warmer south. In general, the highest productivity of sorghum is observed in Southern Europe (Venendaal, et al., 1997).

The crop is adapted to poor soils, though on fertile soils considerably higher yield can be obtained. Plantations of sorghum can be easily and cheaply established by seeds. The crop fits well into conventional crop rotation and, because of high sugar content, sorghum is used for ethanol production. Before sorghum plantation establishment, availability of water should be investigated. One possible option is irrigation with wastewater. Since sorghum is an annual crop, long-term stability of Common Agricultural Policy does not influence the crop cultivation. Production costs around 48 €/odt in Spain and 65 €/odt in France was indicated (Venendaal, et al., 1997).

From an operational point of view, sorghum presents some difficulties (Appendix 3): difficult to find diseases resistant seeds; specific harvesting equipment is required; due to high moisture content and low bulk density, transportation cost is high and fermentation can initiate during storage. To be successfully introduced into energy crop production system, not only energy balance aspect is important, but also some technical constraints should be resolved (Venturi and Venturi, 2003).

3.4.4 Comparison of crops for ethanol production

The output of ethanol dedicated crops in Europe increases from the north to the south and from the west to the east because of climatic conditions and the differences in agricultural techniques. Input for the winter grains is lower than for the summer ones (Table 3). The relationships between lower input – lower output is more favourable for sugar beet and sweet sorghum, which means that with an equal decrease of input, the decrease of output will be smaller for the two crops (Venturi and Venturi, 2003). Table 3 presents only agricultural stages and does not cover the whole alcohol production chain, for which the energy ratio obviously will be lower.

Table 3. Energy input and balance for the most important ethanol production crops in Europe.

Crops	Inputs, GJ/ha			Energy balance range	
	Low	High	Medium	Ratio, output/input	Gain output- input, GJ/ha
Wheat	15	30	25	1.0 –2.8	0–55
Barley	10	28	22	1.5 –2.1	5–32
Sugar beet	25	60	35	2.8–3.2	45–130
Sweet sorghum[a]	15	50	40	6.6 –9.0	85–400

Source: (Venturi and Venturi, 2003). a – data from experimental fields.

3.5 Choice of energy crops

Crops not usually associated with bioenergy such as for food, fodder, pulp production etc. can also be introduced for energy purposes.

Production and establishment costs for the crops, covered in this study, are summarised in Table 4.

Table 4. Establishment and production costs for selected energy crops in Europe.

Energy crop	Establishment costs, €/ha	Production costs, €/odt
Willow		59
Poplar	1600	
Eucalyptus		46
Miscanthus	32-977	
Reed Canary Grass		59-66
Cynara		24-44
Hemp		84
Rape seed		140-250
Cereals		61-70
Sweet Sorghum		48-65

However, there are some limitations to this that have their basis in economic and logistic factors. In the most cases, outputs are low, but wide possibilities, based on nationally available techniques exist to improve them. Crops with ratio output/input lower than 2 (oil and ethanol crops) most likely cannot be considered as viable energy crops since energy gain is the most crucial parameter in the choice of species for energy. Considering currently cultivated crops for automotive biofuel production, only sugar beet seems to fit this requirement and be suitable for energy production in many European countries (Venturi and Venturi, 2003).

Existing infrastructures and organisations influence the choice for which (solid fuel, biodiesel or ethanol production) species will be grown. Piero and Gianpietro Venturi (2003) advise to avoid species, for which low output will be obtained with low input because of unfavourable environmental factors or changes in agricultural techniques. So, species should be chosen with regard to environmental conditions.

At present, production of energy crops is usually restricted by land availability rather than energy input. The use of up-to-date techniques and high capacity machinery can greatly increase output and reduce input. However, input is a factor that cannot be lower than a certain threshold. A number of factors affect input, while total energy balance depends on output. Crops with low output are valid for other (food, forage, fibres) but not energy purposes (Venturi and Venturi, 2003).

Larger assimilation of C_4 crops in biomass production should be aimed for because they have much higher biomass output per incident unit of solar energy than C_3 crops, as it was mentioned before, and thus have capacity to produce more biomass per ha. Only in southern Europe, where the climate is warm, these crops can fully reveal their potential. In temperate climates in the most part of Europe, this is not possible not only because of climatic conditions, but also because of the great differences in specific agricultural practice, existing crop rotation etc. (Venturi and Venturi, 2003).

According to Luger (2002), the fact that output/input ratio for solid biofuels is much higher than for liquid biofuels indicates that from an environmental point of view, solid biofuel has much higher benefits compared to liquid biofuels and that's why it should be promoted in long term perspectives, though both solid and liquid biofuels should be developed in parallel for the present.

"Research and development will have to favour the breeding, mechanization or pinpoint certain techniques on a case by case basis. The most important aspect is to make a vast wealth of knowledge available in order to make informed choices.[…] In short, technical aspects are positive, the economic aspects are not, political, legislative and fiscal initiatives are only promises and remain to be seen" (Venturi and Venturi, 2003).

Energy crop cultivation and energy sector must be more integrated in order for biofuels to fit the specification for fuel for heat and power generation. Biomass for energy is required to have low Cl content (corrosive agent), low K and Ca content (they have low melting point and can form layers in the pipes causing fouling equipment), low N (leads to NOx creation) and low moisture content (resulting in caloric yield of fuel). "More R&D is recommended on relation between fuel requirements, selection of most suitable species and agricultural practices" (Luger, 2002).

With all these fuels in mind it appears that cellulosic crops are preferable option for biomass-to-energy chain.

4 Biomass conversion technologies and CO_2 reduction from different biomass applications

The EU member states have committed themselves under the Kyoto Protocol to reduce CO_2 and other GHGs emissions by 8% (272 Mt of CO_2) by 2010 compared to 1990 level. The level of CO_2 emissions was reduced by 3.5% in 2000, but after that it has started growing and, according to assessment made by experts from the "Shared Analysis Project", in 2010 will be 7% level higher than in 1990 (European Commission, 2001b). Thus, in fact, we are talking about efforts required to reduce CO_2 emissions by 15% (or 544 Mt in actual figures). Thus, the increase of the use of renewable sources in energy production from 6 to 12% provides 200 Mt reductions of CO_2 emissions (European Commission, 2001b). The increase of the use of renewable energy sources together with high energy efficiency could promote the decrease of larger amount of CO_2 emission from energy generation and use. "The use of biomass to produce energy is only one form of renewable energy that can be utilised to reduce the impact of energy production and use on the global environment. As with any energy resource there are limitations on the use and applicability of biomass and it must compete not only with fossil fuels but with other renewable energy sources such as wind, solar and wave power" (McKendry, 2002b). Bioenergy production and utilisation also requires the existence of infrastructure.

The following main biomass - energy chains can be considered:

- the use of dry products (cellulosic crops and residues) for thermo-chemical conversion (gasification, pyrolysis);

- the use of crops (oilseed rape, sunflower, sugar beet, cereals etc.) for liquid biofuel production;

- the use of wet products for anaerobic digestion (with obtaining of methane) or HydroThermal Upgrading.

A wide range of different types of biomass sources as well as significant numbers of conversion options of biomass to energy and end-use application exist (Appendix 4). The choice of a process is conditioned by the type and quantity of biomass feedstock, desired form of energy, environmental requirements and economic conditions. In many cases the process route is determined by the required form of energy and then the quantity and type of biomass (McKendry, 2002b).

4.1 Utilisation of solid biomass for heat/power generation

The demand for electricity in EU is projected by European Commission to increase in the nearest future (European Commission, 1999). Two technological schemes exist: direct biomass combustion, including co-firing with fossil fuel, and the gasification route. The latter is more advanced and promising with respect to the system efficiency.

4.1.1 Direct combustion system

Combustion of biomass is used to convert the energy stored in chemical bonds in biomass into heat, mechanical power and electricity using a variety of equipment: furnaces, boilers, steam turbines etc. Hot gases with temperature of 800-1000°C are generated as a result of the combustion process. Any type of biomass is suitable for burning, but in practice it is restricted by moisture content < 50%, otherwise biomass should be pre-dried (McKendry, 2002b). The most of biomass electricity generation is based on steam-Rankine cycle. Biomass is burned in a boiler to produce pressurised steam, which expands in a turbine to produce electricity. If production of power is the only aim, then a fully condensing turbine is utilised, whilst for heat and power production a condensing-extraction or backpressure turbine is employed. The residual heat can be used for heating or drying of an agricultural raw material.

Electricity generation from biomass via combustion and steam cycle is a well established technology. A steam cycle at a small scale is not an attractive solution due to low efficiency (max 20%) and large investment (1 M€/MW installed for 1-5 MW system capacity) (Berna, 1997). Electrical efficiency of 1-10 MW_e[9] installations is 20-30%, though the ratio power/heat usually does not excide 0.4-0.5. Thus, biomass-base steam cycle power generation can be a viable option if heat/steam are demanded (Salomon Popa, 2002). Combustion in the large power stations with a capacity >50MW displays higher efficiency and relatively lower investments. In such systems old grate-combustion systems are gradually being replaced by fluidised bed boilers. Increased steam conditions result in efficiency 35-40% (for a 50 MW plant). Construction of a biomass combustion plant is very similar to the one using fossil fuel with the exception of a boiler where a lower energy density and higher moisture content of biomass compared to fossil fuel affects the morphology (Berna, 1997).

Heat and power generation using exclusively agricultural biomass feedstock would require the necessity of erecting a large number of decentralized plants. Such work would take time, entail requirements of high investments and large fuel storage facilities (due to the seasonality of biomass supply, as biomass is not harvested year round but just only once or twice in a year) (Hein, Bemtgen, 1998).

Co-firing of biomass in thermoelectric power stations with fossil fuel (generally coal) is a simple and more efficient method of energy generation. Co-firing can be defined as simultaneous combustion of different fuels in the same boiler. There exist three technological options for co-firing: direct, indirect and parallel ones. Direct combustion means combustion of fuel mix in the same combustion chamber. Indirect co-firing is combustion of previously gasified biomass with fossil fuel. Parallel co-firing is separate combustion of fossil fuel and biomass in two boilers (EUBIONET, 2003a).

Characteristics of biomass and coal differ considerably. Wood-based biomass contains around 80% volatile matter, while coal has only 30%. Biomass usually has high moisture content leading to relatively low net caloric value. Properties of wood fuel (ash content, chemical composition of ash, ash melting behaviour) also set a number of requirements to power plant design. The presence of other fuels, especially chlorine containing ones, can also boost fouling formation on boiler and heat transfer surfaces (EUBIONET, 2003a). The relationship between fuel properties and challenges required to be overcome to burn those fuels are displayed in Appendix 5.

Boilers using fluidised bed technology are the most flexible approach for combustion of different types of fuels. Relatively small investments are required to convert a fluidised bed boiler designed for using coal into coal/biomass co-firing one. Any fuel can be used in such kind of boilers provided that it has sufficient caloric value to heat the fuel, dry it and pre-heat combustion air. Fuel-to-steam efficiency of typically over 90% is achievable even with low grade fuel. High efficiency is achieved as the bed, consisting of hot sand and ash by 90%,

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[9] W_e stands for Watt of electricity

circulating in the system and provides very fast heat transfer to the remaining 10% of fuel (EUBIONET, 2003a).

Biomass can also be utilised in the existing pulverised coal-fired power plants, allowing utilisation of local biomass resources. Biofuel can be fed into the boiler together with coal if the share of biomass is low. This is the simplest and the cheapest option, requiring the lowest investments, however, the feeding system should be adjusted. More complicated option is the separate handling, comminution and feeding of biomass into the main upstream fuel flow. The highest investment cost is required when biomass is combusted in a number of dedicated boilers. However, this solution is the safest with regard to normal boiler operation. All these options result in a certain loss of power output compared to mere coal-firing power generation. Gasification enables the use of a larger share of biomass in pulverised coal-fired boilers. Biomass is processed in a gasifier and the resulting gas can be burned together with coal or natural gas in boilers or gas turbines. However, necessary clean up (cooling and filtering, removing of alkali metals and chlorine) in the gas leads to the increased investment costs. Non-cleaned gas can also be burned, but tar and dust will form deposit layers on the inner surfaces of the equipment (EUBIONET, 2003a).

The use of biomass as a substitute for coal provides direct carbon emission reduction 0.5-0.6 tonne of C per each tonne of biomass used (assuming carbon content of coal 76-87% and net energy value for biomass and coal 18.5-20 MJ/kg and 26-28.3 MJ/kg respectively) (EUBIONET, 2003a). Assuming yield of biomass feedstock from dedicated plantations at 10 dry tonne per hectare, each hectare can save 5-6 tonne of carbon (18-22 tonne of CO_2). Utilisation of the most perspective high yield energy crops (for example, miscanthus, giving 20-30 dry tonne per hectare) can cut carbon emission down by 2-3 times more per ha.

For the biomass-firing power production plant of 50 MW_e output and conversion efficiency of biomass to electricity 40%, total energy input would be 125 MW. Assuming annual operation time of such a plant 6000 hours, total capacity would constitute 750 GWh, or $2.7*10^6$ GJ. Taking wood energy content at 19 MJ/kg (19 GJ/ton), such a plant for its year operation would require 142 000 dry tonne of wood. Taking into consideration that 1 tonne of wood used instead of coal leads to 2 tonne of CO_2 emission avoidance, such a plant running on biomass only would save 284 000 tonne of CO_2 (during combustion). As it was stated at the beginning of the chapter, according to Kyoto protocol, EU Member States should reduce CO_2 emission by 2010 by 8% (272 Mt in actual figures) compared to the level of 1990. If this goal is to be achieved solely by the measures taken in power generation, around 960 plants with production capacity 50 MW_e fueled by biomass would be needed. This number of plants is big and unlikely to be constructed.

Carbon emissions related to the fuel chain of modern coal firing power plants are estimated at 1054 g/kWh_e, and for the natural gas fuel chains with CHP at 411 g/kWh_e. CO_2 emission for bioelectricity chains varies widely. Biomass for power generation is 95% a fossil free resource (Boman, Turnbull, 1997; Mann, Spath, 1997). Estimation of Bauen, et al. (2004) of net emission for electricity from short rotation forest is at 44-109 g/kWh_e and from forest residues at 8-16 g/kW_e. Considering the case when coal is replaced by biomass, cost of carbon emission avoided would range 200-400 $US per tonne of carbon (55-110 $US per tonne of CO_2) (Watson, et al., 1996, 41).

Biomass utilisation can also contribute to the decrease of NOx and SOx emissions in the flue gases due to the influence of mineral content of biomass ash. Elements such as Ca, Na, K have a catalytic effect resulting in N_2O reduction. Calcium compounds also work as sorbents for SOx. Wood has low content of sulphur and nitrogen and blending coal with biomass decreases SOx emission also by dilution (EUBIONET, 2003a).

Unlike fluidised bed combustion, where relatively high percentage of biomass in the fuel mix and high moisture content of biomass are acceptable, pulverised fuel plants are limited to 5-10% biomass share in fuel mix (EUBIONET, 2003a).

Biomass-dedicated combustion plants generate electricity with the cost range 60-120 €/MWh depending on combustion technology used and feedstock cost. Co-firing technologies make possible the achievement of bioelectricity generation with much lower costs. Gasification technologies can bring costs down ever further mainly due to higher conversion efficiency. Future costs of electricity derived from dedicated plantations are projected at 50-60 €/MWh

4.1.2 Gasification system

Gasification implies the partial oxidation of organic materials with oxygen supply below stoichiometric ratio[10] under a temperature of around 900°C. The heat required to run the process can be generated by burning of a part of the biomass feedstock. Several types of gasifiers are available with process temperatures in the range from 700 to 1500°C.

Gasification has application in several market segments:

1. a gasifier as a pre-treatment step before an existing power plant (co-firing);
2. small scale fixed bed gasifiers for CHP;
3. Integrated Gasification and Combined Cycle (IGCC) for Power (BioMatNet, 2001).

A fixed bed counter current gasifier is the simplest type of gasifier with several construction features. The biomass usually moves in downward direction, while air can be supplied from the bottom (counter current), from the top or the sides. Such gasifiers have different efficiencies, advantages and drawbacks, and thus can be applied in a variety of needs. In case of counter current flows of biomass and air, fuel is dried inside of gasifier making acceptable higher initial moisture content (up to 60%) of fuel and size variation of fuel feedstock. Fixed bed gasifiers are usually applied for power generation with output in a range 80-500 kW_e or more. The main problem of such gasifiers is that they don't produce tar-free gas. However, this does not present a problem if produced gas will be directly burned for heat generation. Otherwise, for the further application in engines, extensive cleaning is indispensable (European Biomass Gasification Network - GasNet, 1995).

Fluidised bed gasifiers were developed to overcome some problems arising during operation of fixed bed gasifiers, especially high ash content of gas fuel. Such kind of gasifiers appeared to be suitable for the large scale capacities (over 10 MW_{th}[11]). Design of fluidised bed gasifiers is similar to the one for fluidised bed combustion (GasNet, 1995).

Gas turbines for power generation at a large scale (over 5 MW_e) are an attractive option. The gas produced has to be supplied to the combustion chamber under pressure 10-25 bar (this

[10] stoichiometric ratio - the ratio of chemical substances necessary for a reaction to occur completely.

[11] W_{th} stands for Watt of thermal energy

varies for different gas turbines designs). Since the gasifiers normally operate at the atmospheric pressure, the produced gas has to be cooled down and compressed. The latter operation is a very energy intensive one (GasNet, 1995). Cooling is an important operation due to number of reasons:

- gas for combustion has to be free from tar, dust, low-temperature melting salts that otherwise would condense and form foul, but filtering equipment tolerates temperature up to 250°C (EUBIONET, 2003a);
- temperature of gas increases during compression;
- temperature resistance of compressor is limited;
- hot gas takes larger volume than cool one, so additional energy is required to compress it (GasNet, 1995).

Alternative option of having compressed gas is running of the gasification process under pressure. In this case, internal power consumption is lower, while electrical efficiency is higher, but the fuel feeding system is more complex and cleaning devices working under high temperature are required (under development) (GasNet, 1995). Due to complexity, investment costs for a pressurised gasifier are higher, but this can be offset by larger efficiency, especially for power plants with capacity over 50 MW_e (Kaltschmitt, Rösch, and Dinkelbach, (eds.), 1998).

Flue gases after the gas turbine have high temperature that also leads to significant losses in the system[12]. Large scale gas turbines may reach efficiency 40% in the simple cycle, while for medium and small scale efficiency ranges from 20 to 35%. Efficiency can be improved by utilising of exhaust gases for heating of combustion air (GasNet, 1995).

A new and innovative idea is combination of gasification process with heat and power co-generation. Integrated Gasification Combined Cycle (IGCC) is seen as a final concept of conversion process of biomass into electricity, as "the star concept of the future, and its tests and verification will be useful for the future", however "development and implementation however is complex, as it involves all components from fuel to power in the gasification system" (BioMatNet, 2001). Since electricity consumption grows and heat demand for industry and district heating does not increase significantly, the need of higher power/heat ratio was the driving force for the development of IGCC concept at the end of 80's (GasNet, 2002). Gasification is flexible in the fuels used and in combination with CHP can generate almost as much as twice more electricity compared to boiler systems. Estimated efficiency is

[12] Hot flue gases can also be used for steam generation with further application in steam turbines. Steam injection into the turbine of gas turbine (Steam Injection Gas turbine – STIG concept) or into separate steam turbine (Steam and Gas turbine – STEG concept) are further options for steam utilisation. The STEG concept is more complicated than STIG, which lies in continuous water supply to make steam because used steam is released into the atmosphere, but electrical efficiency is higher because in STEG concept steam can be expanded to a larger extend, up to vacuum, and efficiency of steam turbine is higher compared to gas turbine. 55% overall efficiency of STEG cycle is achievable now and up to 60% is projected in a few years. Moreover, water and steam are in close cycle. Hence, STEG cycle is preferred option of the two (GasNet, 1995).

A back pressure steam turbine, which supplies process steam, can be applied in combined heat and power generation plants. "A condensing/extraction turbine may provide flexibility in a CHP concept, as the steam can both be extracted to be used as process steam, or be expanded completely to the condenser and fully utilised for power production" (GasNet, 1995).

around 44-50% (GasNet, 1995). To be economically viable, an IGCC CHP plant has to be of a capacity of at least 15 MW_e (Hansen, 2003).

The energy ratio[13] of a biomass fuel chain ending in IGCC with gas and steam turbines is calculated to be 8 for just electricity production and 15 if case of combined heat and power generation (Bauen, et al., 2004).

Some specific characteristics of biomass – it is a dispersed form of energy, has lower energy content and higher moisture content compared to fossil fuel, low bulk density – should be taken into account when promoting bioenergy into the electricity market. It makes biomass typically a local primary energy source since the long transportation distances considerably raise the cost of produced energy (OECD, 2000). So, decentralized small scale co-generation power plants could be a reasonable solution. Biomass utilization on CHP plants can take place in a range of 0.5 – 1200 MW_{th}, over which co-firing is an option (Fischer, 2003). At small scale, fixed bed gasifiers have advantage. With a biomass cost of 2 $US/GJ, electricity cost from small scale facilities can be in range 10-15 c$US/$kWh_e$ (Watson, et al., 1996, 41). Data regarding investments required and the cost of bioelectricity with utilization of different technologies are presented in Table 5.

Table 5 Overview of investments, efficiencies and production costs of bioelectricity in comparison with traditional technologies using fossil fuel.

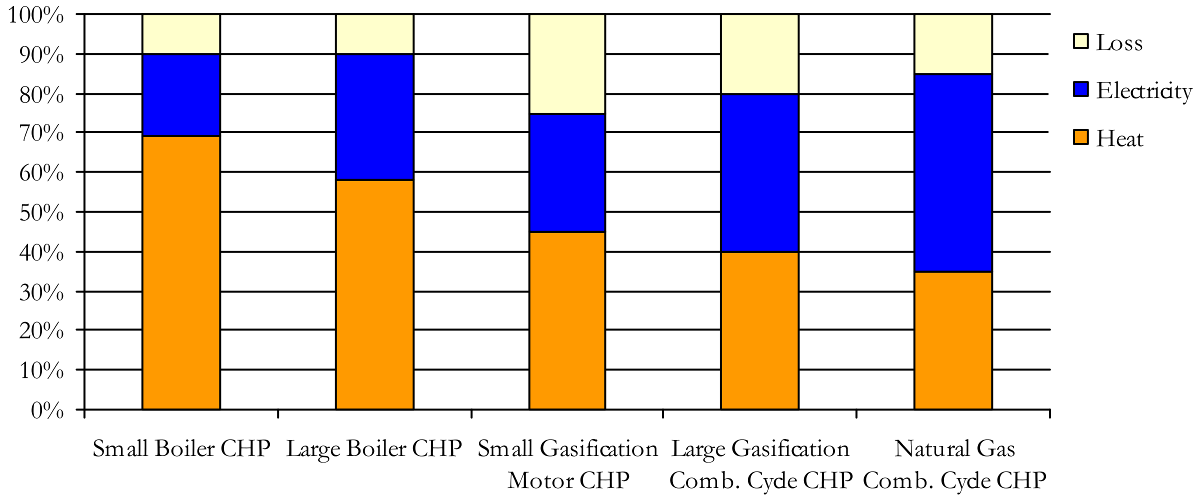
Power generation technology	Capital cost, €/kWe (2002)	Capital cost, €/kWe (2020)	Electrical efficiency	Cost of electricity (2020), €/kWh
Existing coal - co-firing	250	250	35-40%	0.024 – 0.047
Existing coal – parallel firing	700	600	35-40%	0.034 – 0.059
Existing natural gas combined cycle – parallel firing	700	600	35-40%	0.034 – 0.059
Grate / fluid bed boilers + steam turbine	1500-2500	1500-2500	20-40%	0.057 – 0.14
Gasification + diesel engine or gas turbine	1500-2500	1000-2000	20-30% (50kWe – 30MWe)	0.050 – 0.12
Gasification + combined cycle	5000-6000	1500-2500	40-50% (30MWe – 100MWe)	0.053 – 0.10
Pulverised coal - 500MWe	1300	1300	35-40%	0.048 – 0.050
Natural gas combined cycle – 500 MWe	500	500	50-55%	0.023 – 0.035

Source: Bauen, et. al., 2004.

Comparison of fuel utilization efficiencies in different CHP plants is presented in Figure 3.

[13] See the explanation of "energy ratio" on the page 17

Figure 3 Fuel utilisation efficiency on different CHP plants.



Source: Rensfelt, 2002.

Gasification is an efficient technology of clean electricity generation and the starting point for production of a number of other biofuels (as will be discussed in the following sub-chapter), however experience of integration of gasification and electricity production in a scale over 10 MWe is rather limited (Bauen, et al., 2004).

4.2 Biomass conversion into liquid biofuel

Energy demand by transport in Europe is expected to increase resulting in higher air emissions despite improved energy efficiency of vehicles. Biofuels can help to reduce those emissions as they have much lower "well-to-wheel" CO_2 emissions compared to fossil fuels. Serious consideration of liquid biofuels for replacement of fossil diesel and gasoline began several years ago due to national and European policies setting targets of CO_2 emissions reduction. It is because biofuels do not create additional emission except the one on production stage and during transportation of biomass and distribution of manufactured biodiesel. Even on the named stages CO_2 emission could be reduced if machinery is powered with biofuel.

Thuijl, Roos, Beurskens (2003) provide several available pathways from raw biomass to ready-for-use automotive fuels[14]:

- direct conversion process - extraction of vegetable oil with following etherification (biodiesel);
- fermentation of sugar/starch containing crops (ethanol);
- pyrolysis of wood (pyrolysis oil, which is a diesel equivalent);
- gasification of biomass with further conversion of synthesis gas (methanol, dymethyl ester (DME), Fischer-Tropsch liquids);

[14] Biogas as an automotive fuel is not included because raw materials for its production are usually municipal solid waste and manure that are beyond the scope of the present study

- hydrothermal upgrading of wet biomass (HTU oil – equivalent to diesel).

Only the two first fuels are now produced at a commercial scale, while other options are still in the R&D stage and most likely will not be commercially available in the short-term. Ethanol (and ETBE, derived from it) and biodiesel (mainly RME) are used on commercial basis in Europe and will remain the dominant alternative fuels in the nearest future (Thuijl, et. al., 2003).

In this chapter production technologies of mentioned biofuels will be described. Special attention will be paid on two the most popular biofuels, though some technological moments with regard to other possible option will be mentioned as these currently "not economic" fuels may become cheaper and of larger importance later. Information in this chapter will be presented with particular attention on the energy balance of biofuel production, i.e. how much energy is possible to get in form of liquid fuel per each energy unit of biomass input, as well as to what extend it would be possible to substitute fossil fuel in the transport sector.

4.2.1 Biodiesel

Biodiesel is manufactured from a vegetable oil extracted from the seeds of several oily crops. The most widely used sources of oil are rapeseed, sunflower, soybean and palm. First step in biodiesel production is oil extraction, which does not differ from the one for food industry. Biodiesel production in Europe is base on rapeseed. 1 tonne of RME can be derived from roughly 1 tonne of rapeseed oil (European Commission, 1994). Oil from seeds can be extracted by pressing or by means of solvents like hexane. The latter technology allows almost 100% yield (Jensen, 2003).

Pure vegetable oil can be used directly as an automotive diesel fuel, but its properties like high viscosity and low thermal and hydrolytic stability, as well as low cetane[15] number, lead to necessity to process pure oil into a proper fuel to make it suitable for vehicle engines. It is achieved by etherification. The majority of methyl esters is obtained as a result of the catalytic reaction of fatty acids of rape seed oil with methanol. The resulting product is biodiesel. The process in running under moderate temperature (50-66°C) and pressure (around 1.4 bar). Catalysts in reaction of trans-etherification are sodium hydroxide or potassium hydroxide. The mixture of catalyst and methanol reacts with vegetable oil in close vessel to prevent alcohol loss. In 1 to 8 hours the reaction is finished and the reacted mixture is neutralised by adding acid. Non-reacted methanol is recovered for re-use. Resulting two-component mixture – methyl ester and glycerine – is separated. Separation technology is based on difference of densities of the two liquids: glycerine is heavier. After removal of soap, crude glycerine can be used in cosmetic and pharmaceutical industry. Methyl ester is purified by means of washing (to remove residues of catalyst and soap) and distillation to increase concentration from 98 to 100%. Final product is a yellow liquid with much lower viscosity and better long-term storage properties compared to original vegetable oil (Thuijl, et. al., 2003).

Today production cost of biodiesel constitutes about 0.50 €/l (15 €/GJ). Actual price is largely influenced by the cost of feedstock, the size and type of production plant and value of by-products (oil seed cake – a protein-rich animal feed, and glycerine). Short-term investment costs for a plant with thermal input capacity 400 MW_{th} constitute 150 €/kW_{th}, though in long-term these costs are expected to decrease by 30% with enlargement of plant to 1000 MW_{th} due to economy of scale. Calculations, which consider value of by-products in long-term,

[15] cetane number - a number indicating the relative ignitability of a fuel oil for compression-ignition engines. (Source: http://www.websters-online-dictionary.org/)

indicate further reduction of RME production costs up to 0.20 €/l (6 €/GJ) (Thuijl, et. al., 2003).

Biodiesel in the most cases is currently used to power vehicles, but a stationary application (for instance, boilers) is also possible. In the latter case, a burner should be adapted to using of biodiesel, but its utilisation reduce emission and fouling problems.

Due to lower caloric value of RME compared to fossil diesel, 9% by volume (15% by weight) (IEA-AFIS, 1999) more of biodiesel is needed to substitute a certain volume of conventional diesel to power diesel engine.

Assuming that 0.77 ha would be needed to produce 1 tonne of RME, yield per hectare is 1.3 tonne. Based on lower heating value of conventional diesel 42.7 MJ/kg and biodiesel 37.8 MJ/kg, 1.3 tonne of RME can replace 1.15 tonne of fossil diesel. According to Kuznetsov (2000), carbon content of fossil diesel ranges from 85.8 to 87% by weight. Assuming 87%, 1.15 tonne of diesel contains 1 tonne of carbon, resulting in 3.67 tonne of CO_2, emission of which would be prevented by combustion of 1.3 tonne of biodiesel. Net CO_2 emission of 1 tonne of biodiesel is lower due to emissions released on agricultural and processing stage, where fuel used has mostly fossil origin. Actual figure is around 2-2.5 tonne of CO_2 avoidance per 1 tonne of biodiesel (Liempd, 2002). Net renewable energy content of biodiesel (RME) in the final product is 65-70% (Mirandola, 21 July 2004). With production cost 0.5 €/l (0.57 €/kg, considering density of biodiesel 0.88 kg/l), cost of 1 tonne CO_2 avoidance would be around 220-280 €.

Diesel consumption in EU in 1998 constituted 126 613 kt (Liempd, 2002). Assuming thermal input capacity of biodiesel production plant at 400 MW_{th} and 6000 hours of annual operation, total capacity would be 2.4 TWh. 1kWh corresponds to 3.6 MJ. Taking into consideration lower heating value of biodiesel and assuming conversion efficiency of feedstock to RME at 50%, such a plant can produce around 110 kt of biofuel per year, which constitutes 100 kt of diesel equivalent. 5.75% of transport fuel aimed by European Commission to be replaced by biofuel corresponds to 7280 kt. So, 70-80 of 400 MW_{th} plants would be needed to produce sufficient amount of biodiesel. This number of plants is not so large for EU-15, but unlikely achievable. The anticipated constrain for production of 7280 kt of biodiesel is the feedstock supply, for which circa 7 million ha of land is required, which is not possible to provide.

4.2.2 Ethanol

At the present time, ethanol is produced from agricultural sugar- (sugar beet, sweet sorghum) and starch- (cereals, corn, potatoes) containing cops. The easiest feedstock to use is sugar crops, while starch must be converted into sugar prior to be in suitable form for fermentation. Average ethanol yield constitutes from 2.1 to 5.6 m^3/ha depending on a species used. On the top of this range is sugar beet, on the bottom are cereals. To produce 1 tonne of ethanol 3 tonne of grain is required (Thuijl, et. al., 2003).

Crops containing simple sugars are crushed to separate sugars and make them available to the yeast for fermentation. In starch-containing crops carbohydrates are more complex and must be broken (hydrolysed) into simple sugars. Process starts with grinding of grains to free starch. Water is added in certain amount to adjust concentration of carbohydrates and cooked to dissolve all water-soluble substances. During latter process starch converts into sugar by enzymes or acid hydrolysis (in this case diluted mineral acid is added to the mixture before cooking). Resulted simple sugars are fermented by yeasts at slightly acidic conditions (pH 4.8-5.0). Produced ethanol is diluted in water and its concentration is raised trough distillation and dehydration processes. Large amounts of CO_2 are generated during fermentation. Emitted CO_2 is captured and can be used in food industry (Thuijl, et. al., 2003).

Present researches are focused on the utilisation of cellulose as a feedstock for ethanol production due to number of reasons:

- abundant amount of cellulosic material is available;
- cost of feedstock is cheaper compared to conventional raw material;
- cellulosic materials are not used for food production, there would be lower competition for resources with food-dedicated vegetables, mainly for land, but not for actual feedstock; that will also influence production costs since cellulose is much cheaper or does not have any economic value if it is waste stream;
- energy balance is higher than for primary for-food dedicated crops (Thuijl, et. al., 2003).

Cellulose is a material more difficult to convert into sugar and currently production cost is high and not competitive compared to traditional ethanol sources. Production of 1tonne of ethanol needs 2-4 dry tonne of wood/grass (Thuijl, et. al., 2003).

Cellulosic material contains fermentable (cellulose 40-60% and hemicellulose 20-40%) and non-fermentable (lignin 10-25%) parts. Ethanol production from cellulose differs from described above on the stage of hydrolysis of long cellulose chains to obtain simple fermentable sugars. Several pathways exist to perform this operation (Thuijl, et. al., 2003).

The oldest method is the hydrolysis with diluted acid. 0.5% acid is used to break hemicellulose, relatively easily hydrolysable part of lignocellulosic biomass, to simple sugars. The process is running under temperature 200°C. More rigour conditions - 2% acid and 240°C - are required to do the same with cellulose since it is more resistant (Thuijl, et. al., 2003).

More modern method lies in the use of cellulase enzymes to break down cellulosic chains. On the early stages of technology development, enzymatic treatment was utilised to replace acid hydrolysis to split cellulosic polymers. Glucose yield with enzymatic hydrolysis is higher compared to acid hydrolysis. Fermentation of obtained sugars is a separate stage. Later, simultaneous saccharification and fermentation, when both processes take place in the same moment in the same vessel, was introduced. This approach results in reduction of the number of reaction vessels required. Additional benefit of such a process is avoidance of several constrains faced with separated hydrolyse and fermentation like sugar accumulation and enzyme inhibition (Thuijl, et. al., 2003).

In all cases, fermentation and distillation processes are identical. To be used as transport fuel, water content in ethanol should be reduced to close to zero in order to reduce corrosion properties of the fuel. So, dehydratation stage is highly required. Overall energy efficiency and economic performance can be improved if non-fermentable part of feedstock is used for heat/electricity generation (Thuijl, et. al., 2003).

Production technology from these sugar/starch containing crops is relatively mature and most likely will not be improved to decrease production costs. Up to 80% of production cost is the cost of feedstock. Short-term investments for ethanol production from sugar-containing crops are estimated at 290 €/kW$_{th}$ for a plant of 400 MW$_{th}$ input capacity. For woody material processing into ethanol, production cost is 350 €/kW$_{th}$ for the plant of the same capacity. In long-term perspectives, production cost is going to decrease with enlargement of plant to 1000 MW$_{th}$ due to economies of scale for woody feedstock by 50% and sugar- crop feedstock by 40%, though in latter case fuel production efficiency is not expected to increase. Production cost of ethanol from sugar beet is about 0.32-0.54 €/l (15-25 €/GJ). Production cost from cellulosic material is estimated at 0.11-0.32 €/l (5-15 €/GJ), lower cost is for advanced technologies (Thuijl, et. al., 2003).

Due to the lower caloric value of ethanol compared to fossil petrol (21.2 and 31 MJ/l respectively) (Thuijl, et. al., 2003), much higher amount of alcohol is needed to substitute a unit of petrol.

Let's calculate how many plants of input capacity 400 MW$_{th}$ would be required to replace 5.75% of fossil fuel in EU by 2010. 105 676 kt is the amount of petrol, delivered to gasoline stations in EU-15 in 2002 (Eurostat, 2003). Assuming 6000 hours annual operation of such a plant, total capacity would be 2.4 TWh. 1kWh corresponds to 3.6 MJ. Taking into consideration lower heating value of ethanol and assuming conversion efficiency of feedstock to ethanol at 50%, such a plant can produce around 200 mln litres of ethanol per year. This volume of ethanol is equal to 137 mln litres (around 103 kt) of fossil petrol in heat content. 5.75% of delivered petrol is 6076 kt. Dividing total annual amount of petrol required to be replaced on 103 kt, approximately 60 plants (not so large number for EU-15, but unlikely achievable) would be needed to fulfil alternative fuel introduction on EU market of fuel for spark ignition engines.

Assuming ethanol yield per hectare of wheat and sugar beet at 2 and 5.6 tonne respectively, it would replace 1.3 and 3.6 tonne of petrol. With carbon content of petrol at 86% (Kuznetsov, 2000), emission of 1.1 and 3.1 tonne of carbon, or 4.1 and 11.3 tonne of CO_2 could be theoretically prevented by utilisation of ethanol for utilisation in internal combustion engine from 1 hectare of wheat and sugar beet respectively. Net avoided CO_2 emissions will be lower due to the use of fossil fuel on agricultural and processing stages of ethanol production. As derived from (Coombs, 1996), ethanol from wheat is renewable fuel just on 20-40% depending on system efficiency. Utilisation of straw and other agricultural residues for heat and electricity production to run process would definitely positively affect net CO_2 emission and may also cut production costs. In case of ethanol from sugar beet, with production costs 0.32-0.54 €/l (0.4-0.68 €/kg), CO_2 abatement cost would constitute around 450-750 €/ton, considering net CO_2 emission avoidance 5 ton/ha.

The study (Coombs, 1996) claims that relatively small percentage (around 5%) of ethanol in a petrol-ethanol blend will not affect fuel consumption because lower heating value of alcohol will be offset by its octane number boosting property and compensate any loss of power. Thus, 5% blend will result in 5% reduction of CO_2 emission from a vehicle. Since ethanol production requires a lot of fossil energy input, actual net CO_2 avoidance (ethanol from wheat) will be around 1% (assuming energy output/input ratio 1:1), which increases with the increase of system efficiency. Actual net energy ratio is close to 1 that can be raised to 2-3 if straw is processed. System efficiency for ethanol from wheat constitutes around 7-10% with consequent low net fossil fuel replacement. In case of ethanol from wood, energy efficiency can be up to 60%.

Thus, environmental end energetic viability considerably depends on by-products and co-generated waste processing.

4.2.3 Pyrolysis oil, HTU oil, methanol, Fischer-Tropsch diesel

Pyrolysis oil is an almost black coloured liquid that is formed in the result of conversion process called flash pyrolysis – fast thermal processing with the absence of oxygen. The resulting liquid can be used for variety of applications including manufacturing of diesel substitute. Feedstock for pyrolysis is any type of biomass (Thuijl, et. al., 2003).

With absence of oxygen, biomass is not burning but transforms into bio-oil, char and gases. Exact composition of products depends on process temperature, heating rate and residence time. Slow pyrolysis, the main product of which is charcoal, runs at 400°C with very low heating rate and long residence time (hours-days). At the higher temperature, gas, oil and char are generated in equal proportions. Fast pyrolysis, resulting in pyrolysis gases, char and vapours, condensed to bio-oil, runs under temperature 500-650°C; residence time constitutes seconds. Flash pyrolysis takes place at 700-1000°C; residence time is less than a second. To be suitable for pyrolysis, biomass must be grinded to the particle size less than 6 mm, and dried. Products of pyrolysis are separated: char can be burned with heat use for drying of feedstock. Vapours are rapidly cooled to produce bio-oil. Non-condensed part of gaseous phase can be recycled as fluidising gas, or combusted in a gas engine (Thuijl, et. al., 2003).

Pyrolysis oil can be utilised for co-firing in electricity generation plants or used as a feedstock for synthesis gas production with further conversion to methanol or Fischer-Tropsch liquid. To be used directly in automotive engine, bio-oil should be upgraded and stabilised. The utilisation in stationary applications like boilers or engines instead of fossil oil is also possible (Thuijl, et. al., 2003).

Due to chemical composition of pyrolysis oil, it is rather valuable raw material for non-energy use: polymer manufacturing, production of pharmaceutical preparations, pesticides, resins, surfactants. Non-energetic application of bio-oil is currently in focus of technological development of pyrolysis oil production (Thuijl, et. al., 2003).

Hydro Thermal Upgrading (HTU) is a process of decomposing of biomass in water, the product of which is crude oil-like liquid. The broad range of feedstock is suitable for HTU, but this process is especially favourable for wet biomass: beet pulp, bagasse, sludge. Dry or wet biomass reacts in water under pressure around 120-180 bar and temperature 300-350°C. Conversion process takes 5-10 min. The main products are bio-crude (50%) and gases (30%), the majority of which is CO_2. The resulting liquid is black coloured viscous mix of hydrocarbons. Light and heavy fractions of bio-crude are separated and can be used for different purposes as energy carriers. Destination of the heavy fraction is in co-firing on coal-based electricity generation plants. The light fraction is very clean and the best suitable for production of diesel fuel components. For this, upgrading of bio-crude lies in hydrogenation, that is rather energy intensive process and thus unfavourable from economic point of view (Thuijl, et. al., 2003).

Thermal efficiency of the HTU is estimated at 80%. If upgrading is performed, from long term perspectives, the efficiency of overall process is estimated at 60%. In short-term perspectives investment costs for a HTU plant are estimated at 95 €/kW_{th} for 400 MW_{th}, though in a long-run they are expected to fall down by 25% for 1000 MW_{th} plant. Upgrading of bio-crude rises investment cost more than 5 folds, to 535 €/kW_{th} for 400 MW_{th} plant with 25% cost reduction in long-term perspectives. The production costs of HTU diesel in a large scale are estimated at 5-7 €/GJ or 0.16-0.24 €/l (Thuijl, et. al., 2003).

Methanol, DME and Fischer-Tropsch liquid can be obtained by gasification route of biomass. Any kind of biomass feedstock is suitable, but dry materials are preferred since the higher conversion efficiency for them is observed. The resulting synthesis gas consists mostly of CO, CO_2, H_2, CH_4, H_2O and N_2. It usually contains some amount of contaminants like char particles, chlorides, sulphates, nitrogen compounds, tar, which decrease activity of catalyst during gas reforming and can cause corrosion of heat-exchange equipment and gas turbine. Exact composition largely depends on composition of biomass and temperature of gasification. So, all unwanted components of syngas should be thoroughly removed before further gas processing. For the synthesis reaction syngas should be conditioned – ratio H_2:CO has to be adjusted for a concrete purposes (2:1 for Fischer-Tropsch liquids and 3:1 for methanol production) since syngas after biomass gasification has lower ratio H_2:CO. Synthesis reaction is the catalytic one, and exact composition of hydrocarbons depends on type of catalyst and reaction conditions. The products are separated from by-products by distillation and usually are very clean (Thuijl, et. al., 2003).

1 tonne of methanol can be produced from approximately 2 tonne of wood (550 l per 1 tonne of wood). In short term, investment costs for 400 MW_{th} methanol production plant are estimated at 700 €/kW_{th}, which could decrease by 25-30% for larger installation. Efficiency is about 50-55% in short term that may increase to 60-65% for 1000 MW_{th} plant in long term assuming partial electricity generation. Estimation of short term production costs is shown at 0.14-0.20 €/l (9-13 €/GJ). Future production costs can drop to 0.10 €/l (7 €/GJ). Methanol can be mixed with fossil fuel and used in diesel engine or, what is more preferred, can replace petrol in Otto engines since it has high octane number. Due to lower volumetric heat content of methanol compared to petrol (15.6 MJ/l and 31 MJ/l respectively), larger volumes of it is required to replace a unit of petrol (Thuijl, et. al., 2003).

Dymethylether (DME) is currently used as a substitution of freons in spray cans and recently started to be considered as a diesel fuel. Both biomass and natural gas can serve as a feedstock for DME production. Around 3 tonne of wood is required to produce 1 tonne of DME (around 500 l of DME per 1 tonne of wood). DME can be produced directly from syngas, similarly to methanol, or by etherification of methanol. Currently DME is synthesised mainly from syngas that has fossil origin (natural gas, heavy oil, coal), while technologies of biomass utilisation are still on development stage (Thuijl, et. al., 2003). Investment costs for commercial plant of 200,000 tons/year production capacity in the project in Sweden were estimated at 390 mln €. Production costs would constitute around 0.27 €/l (14 €/GJ) or around 0.5 € per litre of diesel equivalent since volumetric energy content of DME is almost as much as twice lower than diesel (Swedish National Energy Administration, 2002).

Fischer-Tropsch liquid was initially produced from fossil feedstock, but now it develops in direction of using of biomass as a raw material input. Processing of 8.5 tonne of wood could give 1 tonne of Fischer-Tropsch diesel, or 150 l per 1 tonne of wood. Bio-oil from flash pyrolysis can also be utilised as a feedstock. Synthesis process of Fischer-Tropsch liquid is the catalytic conversion of syngas into a range of hydrocarbons, aiming obtaining long-chain products. Non-converted syngas can be recycled to maximize yield of the main product or utilised for heat and electricity generation on CHP. Fischer-Tropsch diesel can substitute fossil diesel. This fuel can be applied also in Otto engines, but to limited extent – only up to 15% mix with petrol- because of its very low octane number. 66% of investment costs for Fischer-Tropsch liquid production is syngas preparation and only 22% belongs actually to the synthesis process. Total investment costs are estimated at 720-770 €/kW_{th} for a plant of input capacity 400 MW_{th}. In long term for larger installations of 1000 MW_{th} investment costs are like to decrease by 25-35%. Production costs lie in a range 8-13 €/GJ in short term with possible decrease to 9 €/GJ in long term. Fischer-Tropsch diesel is a very good, very clean substitution of fossil diesel and their caloric values are almost equal (34.3 MJ/l for Fischer-Tropsch diesel and 35.7 MJ/l for conventional diesel) (Thuijl, et. al., 2003).

All investment and production costs are summarised in Table 6.

Table 6. Overview of investment and production costs for different liquid biofuels.

Biofuel	Investment costs, short term, €/kW_{th}	Investment costs, long term, €/kW_{th}	Production costs, short term, €/litre	Production costs, long term, €/litre	Production costs, short term, €/GJ	Productio n costs, long term, €/GJ
RME	150	110	0.50	0.20	15	6
Ethanol (sugar crops)	290	170	0.32 - 0.54		15 - 25	
Ethanol (wood)	350	180	0.11 - 0.32		5 - 15	
Methanol	700	530	0.14 - 0.20	0.10	9 -13	7
DME			0.27		14	
Fischer-Tropsch diesel	720 - 770	500 - 540	0.31 - 0.45		9 -13	
Pyrolysis oil (not upgraded to diesel quality)	1,000	790	0.06 - 0.25		4 -18	
HTU diesel	535	400	0.16 - 0.24		5 -7	

Source: Thuijl, et. al., (2003).

It should be noted that only for RME and ethanol from sugar crops those figures are the actual costs. For all other alternative fuels investment and production costs are just estimation that embodies future technology development and significant cost reduction due to economies of scale (large scale production facilities).

4.3 Transportation or power – what option is preferable?

Conversion efficiency of biomass into liquid biofuel lies in the range 50-60%, while efficiency of oil refinery constitutes around 90%. Remaining 10% is the losses in the system and the use of part of oil feedstock to run distillation process (European Communities, 2003a).

According to statistics in the European Communities (2003a, 2003b), around 35% (by weight) of refinery oil intake ends up in diesel fuel and 21% in petrol. 1 hectare of rape gives 1.15 tonne of oil-equivalent fuel, which would result from 3.28 tonne of oil. 1 hectare of wheat produces 1.3 tonne of petrol-equivalent fuel that would require around 6 tonne of oil to distill. So, fuel, which is possible to produce from 6 tonne of oil, could be replaced by biofuel grown on roughly 3 hectares.

Large difference in CO_2 economic avoidance costs for biodiesel and ethanol can be explained by the fact that with similar production cost per liter, energy content of ethanol is 30% lower compared to biodiesel. CO_2 avoidance costs for these fuels are high but they "do not take into account the security of supply and the advantages to the rural economy (diversification, employment). The extra costs for biofuels should also be seen in the light of the value of CO_2 quota within the framework of the Kyoto Protocol" (Liempd, 2002).

Biomass for power generation can be seen as making possible the highest reduction of CO_2 emissions among considered options of biomass application. Co-firing scheme allows getting some benefits of using of renewable energy sources (lower CO_2, SOx, NOx emissions) and generating energy with affordable price. Benefits of co-firing are that an energy plant normally already exists in the area; low-cost residues and waste can be utilised; activity of co-firing power plant will not be affected by seasonal aspect of agricultural production, especially if low cost materials are considered (that can be the case for solely biomass firing plant) (Berna, 1997). Other benefits are better use of local energy sources, decreased amount of waste for disposal and landfill, saving of fossil fuel resources (EUBIONET, 2003a). Large-scale co-firing plants have higher steam parameters, technical measures and system efficiency that result in better potential for high electric efficiency. Overall fuel saving is higher for co-combustion plant compared to the two independent fossil and biomass power plants. Co-firing is considered by a number of studies (EUBIONET, 2003a; Bauen, et al., 2004) as "one of the most realistic ways to contribute to achieving the objective on doubling the share of renewable energy sources in the EU energy balance" (EUBIONET, 2003a).

Biomass gasification is considered as the most perspective way of biomass conversion into power but these technologies are currently commercial on the niche market (small scale gasifiers utilizing specific biomass fuel like waste). Small-scale gasification systems are projected to disseminate in CHP generation and certain industrial applications in the nearest years. Their development in scale-up direction would result in more efficient use of feedstock. Future development could be an integration of biomass gasification facilities with advanced conversion technologies and co-production of liquid biofuels in addition to electricity (Bauen, et al., 2004).

5 Policies promoting biomass development and utilisation for energy purposes

As it was defined in the previous chapter, bioelectricity is the preferable option of biomass application in short to medium perspectives, allowing relatively rapid CO_2 emission reduction in energy sector. Biomass electricity constituted around 10% in EU-15 electricity generation from renewable sources in 2000 (European Communities, 2002b). In this amount only half belong actually to wood utilisation on power stations, while the rest is MSW and biogas. Thus, electricity generation from wood/wood waste and agricultural solid waste represented less than 1% in total electricity generation.

Availability of commercial technologies with high efficiency electricity output is a base for bioelectricity development, but due to higher production costs compared to conventional power generation policies promoting wider bioenergy implementation are required that would facilitate faster and deeper penetration of renewable energy into all sectors of economy. Since bioelectricity generation consists of biomass feedstock production and its conversion into power, relevant supportive policies are necessary on all stages of the cycle. "Therefore, a significant increase in bioelectricity use requires a strong policy commitment and needs to be accompanied by regulations and guidelines that ensure its environmental sustainability" (Bauen, et al., 2004).

5.1 Policies promoting energy crop cultivation

Biomass in the share of renewable energy sources in 2010 is estimated to represent 135 Mtoe, of which additionally to the level of consumption in 1997 (45 Mtoe) 75 Mtoe are estimated to be used for heat and power generation (Commission Communication COM(97)599 final). Since biomass will become a major contributor into a mix of primary energy sources, potential of dedicated energy crops should be exploited wider.

Successful integration of energy, environmental, agricultural and forestry policies conditions successful implementation of bioelectricity. As the provision of biomass feedstock, supply is crucial for biomass energy system development, key role in it belongs to agricultural and forestry policies. The reform of the Common Agricultural Policy in 1992 encouraged the use of agricultural land for non-food crop production (Diamantidis, Koukios, 2000). Set-aside land is an option for enlargement of land area under energy crops and additional source of income for farmers. In 2001, the most of the area of set-aside land for non-food production, that constituted 16% of 5.7 million ha, was used for biofuel production (Bauen, et al., 2004; Council Regulation (EC) № 1782/2003). Promotion of energy crops by the Common Agricultural Policy has been modest, though it's potential to create framework for biomass energy development is under-revealed. The extend to which energy crop can be introduced into agriculture is determined by a number of factors "including agricultural productivity, trade balance, the Western European demand for agricultural products affected by population and the consumption pattern" (Diamantidis, Koukios, 2000).

CAP was initially designed to maintain food production, but now also pays attention on non-food crops. One kind of support to energy crop from CAP is a possibility of their cultivation on set-aside land. New Regulation 1782/2003 is presented as a new and effective farm policy. According to it, aids to farmers will not be linked to production but instead will be in a form of a single payment that is expected to guarantee to a certain degree stable income of farmers and freedom in choice to produce what is demanded by consumers. With regard to energy crops, an annual aid 45 €/ha is proposed by the Commission that can be applied for area maximum 1,500,000 ha. With this payment, energy crops are acknowledged as an important energy resource in promotion of carbon dioxide emission reduction. The aid is granted only provided that production of the area is covered by contract between farmer and processing industry, excluding the case when processing is made by farmer. Proposed aid could cut down production costs of energy crops up to 10% (Bauen, et al., 2004).

Direct payments to farmers are funded by public, actually, by customers. The new solution that would internalize positive environmental impact of biomass on carbon cycle (Kirschbaum, Schlamadinger, Cannell, Hamburg, Karjalainen, Kurz, Prisley, Schulze, and Singh, 2001) and at the same time would not require public money is proposed. The farmers should be given certificates for their land capacity to capture and retain CO_2. These certificates could be sold to CO_2 emitters (e.g. industry) and serve as an extra income to farmers and support them in difficult period when prices for agricultural products fall. As CAP requires keeping set-aside land in good agricultural and environmental condition, green certificates could be seen as a compensation for that (Ruoff, 2003). Standing biomass is a natural carbon sink that would increase provided long-term establishment of biomass energy in agricultural practice (Hanegraaf, Biewinga, and van der Bijl, 1998).

5.2 Policies promoting biomass utilisation for power generation

These kinds of policies could be nominally divided into policies supporting actually electricity generation from renewables and biomass in particular in the most cost effective way, and policies guaranteeing market for bioelectricity.

Having recognized the importance of climate change issue and necessity of GHGs emission reduction, the European Commission has adopted the Community Strategy and Action Plan aiming 15% GHGs emission reduction by industrialized countries till 2010 compared to the level of 1990 (Commission Communication COM(97)599 final). The prominent role in it belongs to renewable energy sources. 12% of renewables in total gross energy consumption, targeted by 2010, has been translated by European Commission into specific goal for electricity form renewable energy sources that is expected to grow to 22.1% in 2010, requiring significant efforts of Member States to develop this target. In particular, the EU Directive 2001/77/EC obliged the States to set national targets of percentage of renewable electricity consumption. This and other supportive measures will be discussed further.

When it comes to policies promoting technological development toward electricity generation, only one policy regarding promotion of combined heat and power generation (Commission Directive 2004/8/EC) is published and actually is in force. As it was identified in previous chapter, biomass co-combustion and biomass IGCC are the most desirable options of biomass feedstock utilization in energy sector, giving possibility to quickly introduce large amount of biomass into power generation (co-firing) and having the highest fuel use efficiency (gasification option). However, those are still on the development stage, thus no specific policies exist. Some ideas of Directive about CHP are given below. Even though this Directive is not specific for biomass energy, it is seen to be in line with Directive 2001/77/EC about promotion of electricity from renewable energy sources, implying that biomass is covered as a feedstock for cogeneration plants.

Combined heat and power generation (simultaneous generation of heat and electricity in a one process) is a very fuel-efficient technology that uses heat, which otherwise would be released into atmosphere. The use of CHP is beneficial from several points of view:

- energy savings. The share of cogeneration in the total EU electricity production in 1998 constituted 11% that resulted in 2% energy savings of the total EU gross primary energy consumption. Increased share of cogeneration to 18% in 2010 would save 3-4% of total EU gross energy consumption, as estimated by the European Commission (European Commission, 2002).

- security of energy supply. Cogeneration entails diversification of fuel mix, increase regional fuel self-sufficiency and rise physical security of energy supply due to autonomic energy generation in various places, thus contributing to the key objective of EU energy policy. High output cogeneration plant allows saving fuel more than 10% compared to separate generation of heat and electricity in the same amount.

- CHP is a cost-effective energy solution, taking into account avoided CO_2 emissions and lower fuel consumption compared to separate heat and electricity generation. According to estimations of experts from European Commission, potential of CHP to reduce CO_2 emissions among EU Member States is identified at 65 Mt, of which 12 Mt could be reduced with the cost 20-50 €/tonne (Commission Communication COM(2001) 580 final). Even though these calculations were made assuming combine cycle gas turbine with electrical efficiency 55%, they are rather indicative, however in the case of biomass feedstock, CO_2 abatement cost would be higher. "Actual reductions, however, are subject to uncertainties because the proposed CHP Directive is a framework Directive leaving the choice of implementation strategy and specific support mechanisms in favour of CHP to each individual Member State" (Commission Communication COM(2001) 580 final).

- there are less losses in the electrical grid since CHP installations are usually located close to the consumption point.

- CHP is a reasonable solution for remote or isolated areas (European Commission, 2002).

Promotion of heat and power cogeneration is a part of the strategy of expansion the utilisation of renewables. Cogeneration is not a target itself, but is an efficient tool to save energy resources and reduce carbon emission. Since generated electricity can be transferred by grid and sold where it is needed, heat is much more difficult to transform and store. The EU Directive 2004/8/EC creates framework to support and facilitate installation and functioning of CHP plants in places where a useful heat demand exists or is expected in the future. In short term, the Directive should serve as an instrument to strengthen existing, to promote construction of new CHP plants and to create a level playing field through regulations and financial support. In the medium to long term the Directive is expected to create framework to ensure high-efficiency cogeneration that is a key element to make decision about new investments into new production capacity.

The success of biomass (and renewables in general) on the energy market is determined by a number of factors (political, financial, fiscal, administrative etc.), among which policy instruments particularly relevant to biomass-derived energy could be paid attention on. The ADMIRE REBUS project team analysed market barriers, potentials and policies to support renewable electricity generation in Europe (Uyterlinde, et al., 2003). Figure 4 shows policy instruments currently adopted by EU Member States to promote electricity from renewable energy sources on energy market.

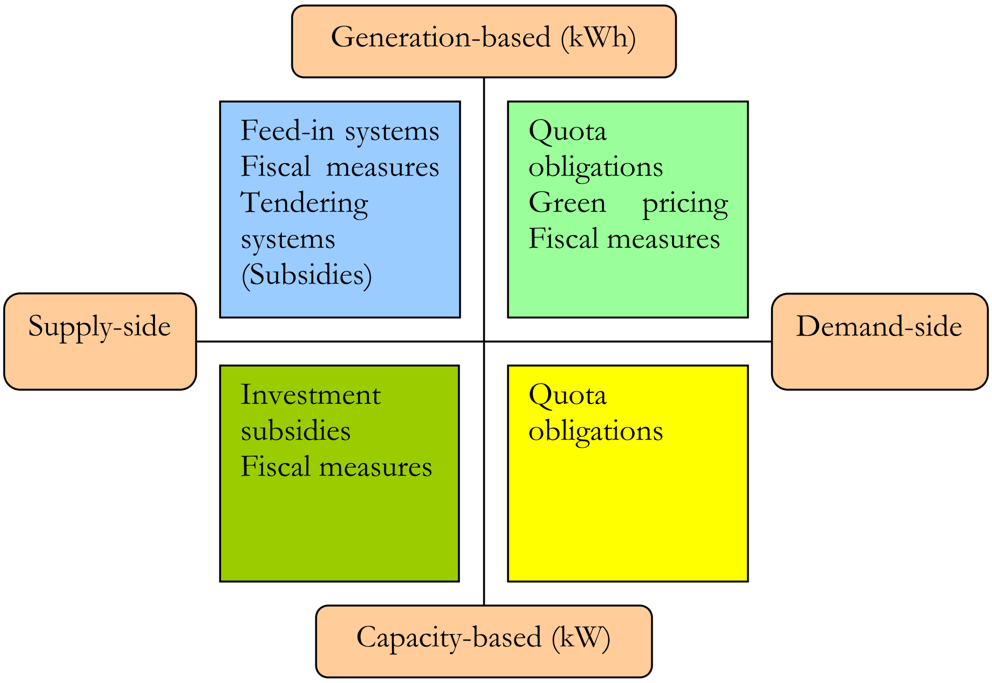


Figure 4 Policy instruments to support electricity generation from renewable energy sources in EU. Source: Uyterlinde, et al. (2003).

General trend towards feed-in tariffs, quota obligations supported by tradable green certificates is observed (Uyterlinde, et al., 2003).

One of the most effective support measures to encourage electricity generation from renewables is the feed-in law. "In this system, an obligation is placed upon utilities to accept all renewably generated power, provided technical criteria are met. The power producers are paid a guaranteed price for their power – fixed according to technology type. This may be financed through a subsidy, from a levy on conventional generation for example, or borne by the utility and passed onto consumers" (Bauen, et al., 2004). Electricity prices in feed-in tariffs are higher than regular electricity market price and are justified as internalisation of environmental, economic and social advantages of bioelectricity. Feed-in tariffs provided long-term financial stability and a certain degree of confidence that is a crucial factor to attract investors. This law has been beneficial for biomass on power stations in particular in Denmark, Germany and Spain (German Federal Ministry for Economic Cooperation and Development (BMZ), German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), 2004; EEA, 2001).

Drawback of feed-in system was that it has provided limited incentives for prices to go down. In Denmark between 1993 and 1999 bioelectricity production growth was 189%, which was lower than expected, because electricity prices did not change during this period and become considered not economically viable. This situation is on the way to be altered by reforms of the electricity industry. On the contrary, in Germany, feed-in law has been introduced in 2000 and has been designed to provide incentives for bioelectricity projects development and the decrease of price with time (EEA, 2001; Bauen, et al., 2004).

The main alternative to the feed-in system is "competitive bidding" ("competitive tendering", Non-Fossil Fuel Obligation - NFFO). "Renewable energy developers are invited to bid for contracts to sell electricity at a fixed premium price for a fixed term. […] The price premium was funded through a levy on conventional generation" (Bauen, et al., 2004). Usually a contract for power sale is for a long term, e.g. 15 years. Competitive bidding for electricity from a range of renewable sources has been introduced in Ireland and the UK (EEA, 2001).

"Renewable Portfolio Standard" (RPS) has been recently adopted by a number of countries. This market-driven policy sets a minimum percentage of electricity generated in the state from renewable energy sources (OECD, 2000). The target has to be met at the certain point in the future. EU Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market sets a target on electricity from renewable energy sources 22% by 2010 (14% in 1997). Targeting is a part of strategies for the future expansion of renewable energy on all levels – local, regional, national – that can, in turn, give long-term overall direction of energy sector development and send signals to the actors on energy market. The exact target is largely influenced by ultimate goal steering by reduction of GHGs emissions reduction, security of energy supply, fair access to electricity etc. (BMZ, BMU, 2004).

Additionally, governments of EU Member States may offer financial support for biomass derived electricity. Fiscal measures can take form of environmental taxes (penalizing the use of fossil fuel) or tax reduction or exemption for environmentally beneficial investments. Environmental taxes are part of state's energy policy, reflecting cost of generated power or heat for the environment. Environmental taxes could be levied on energy use, power or heat generation, CO_2 or SO_2 emissions. In any case, biomass power and heat benefits from these taxes. For example, in Sweden, introduction of carbon and energy taxes, from which biomass has been excluded, promoted significant expansion of biomass into district heating and CHP. Investment into renewable energy can also be promoted by fiscal instruments (EEA 2001).

EU Directive 2001/77/EC confesses that due to limited experience with national schemes of support of renewable electricity development it is too early to create Community-wide framework for supporting mechanisms. However, Member States are encouraged to use different renewable energy supporting mechanisms on the national level "including green certificates, investment aid, tax exemptions or reductions, tax refunds and direct price support schemes".

Access to the grid infrastructure is a critical factor for renewable electricity since renewable electricity is usually generated on small scale facilities and may be located on remote area with limited or unavailable grid connection. Admitting the grid access as an important component of electricity market, EU Directive 2001/77/EC requires Member States to "take the necessary measures to ensure that transmission system operators and distribution system operators in their territory guarantee the transmission and distribution of electricity produced from renewable energy sources". The list of measures to promote biomass electricity in selected EU Member States is presented in Appendix 6.

Due to liberalisation of EU electricity market, the policy context for electricity from renewables is changing over time. To evaluate this and properly correct policies in force, Directive 2001/77/EC obliges the Member States to publish reports every two years, displaying to what extend undertaken measures to meet national targets towards the share of renewable electricity consumption were successful.

Experts from ADMIRE REBUS project assessed that among Member States, only Austria, the Netherlands and the United Kingdom will be able to reach their national targets of renewable electricity provided that present policies continue, while overall EU target will be achieved by 82%. International trade gains increasingly important role. Combination of renewable electricity international trade with mandatory targets for 2010 is seen by ADMIRE REBUS team as the most cost-effective strategy for the EU as a whole. The reason for that is a comparative advantage of some countries over others. Power generation capacities will be installed in locations where they are the most cost-effective, meaning that development potential is available for the lowest cost. Some amount of renewable electricity could be imported for the lower price that generated by domestic installations (Uyterlinde, et al., 2003). This could facilitate achieving set targets as Directive 2001/77/EC says about share of *consumed*, not *generated* renewable electricity. From another point of view, domestically generated renewable electricity can be preferred option over imported one due to reasons of improving national environment, creation additional local employment, diversification of rural business. In any case, measures to reduce energy (and electricity) demand could significantly save costs.

5.3 Policies promoting technological development

Research & Development is a very important phase, not only of the stage of biomass conversion into power (technologies and devices), but also on the agricultural stage of biomass production, where environmental consequences of energy crop cultivation determines whether the crop will be used for mass production. Many European countries have research plots to define proper agricultural practice for each energy crop as they have different requirements of water, input of fertilisers and pesticides, weed treatment etc. (Venendaal, et al., 1997).

In 2004 European Commission published the Third Call for research and development (Commission Call FP6-2004-TREN-3). Development of energy sector for sustainable development is one of the priorities of this Call. Working Program (European Commission, (2004), published in April, explains the main direction where R&D projects should be focused on. The main strategic and policy objectives of this program, among others, are GHGs emission reduction, the increase of security of energy supply, the increase of the use of renewable energy sources and improvement of energy efficiency. In short-medium terms, R&D projects are expected to ease the introduction of innovations in renewable energy technologies with further demonstration (at full scale, allowing making life-cycle assessment under real conditions) to make them cost competitive and bring them into the market. This would also support development and implementation of EU Directives about promotion of electricity from renewables and cogeneration, mentioned above.

With regard to electricity generation as a better option for biomass utilisation, Working Program proposes a number of priorities of researches in the field of bioenergy, such as combinations with fossil fuels (co-firing), innovative technologies for large scale electricity generation (IGCC, biomass gasifiers, boilers, flash pyrolysis). Proposed technologies should be cost-effective, very reliable to guaranty the continuous electricity supply to the consumers, and have high conversion efficiency (European Commission, (2004). Importance of co-firing, cogeneration and biomass integrated gasification combined cycle has been admitted by European Commission in 1997 when publishing Action Plan, defining them as the most desirable technical solution for wider implementation of biomass into heat and power generation to be promoted (Commission Communication COM(97)599 final). Acceleration of cost reduction for renewable energy technologies is vitally important to promote their dissemination on energy market.

The help to develop and launch advanced energy technologies is a crucial area for policy. Government has a major obligation to support R&D in energy sector since private firms cannot fully bear all investment costs. This challenge is widely recognised. Critical mass of successful researches has to be followed by demonstration projects. Demonstration projects are required to show that a new promising technology can be implemented in a large scale. "What is not widely recognized is that government also has major obligations to encourage demonstration projects and early deployment of energy technologies that offer promise in addressing sustainable development objectives, because the market alone will typically not be able to overcome the higher initial costs of new energy technologies" (Goldemberg, Johansson, Reddy, and Williams, 2001). Even if a new technology is proved to be viable, it takes decades before new technology can gain considerable share of the market (Goldemberg, et al., 2001).

6 Conclusions and Recommendations

The question about what constitutes "optimal" allocation of biomass resources for energy purposes is important as resources are limited. The answer depends on which goal of energy policy is pursued.

Considering **carbon emission reduction**, the most beneficial use of biomass energy with current available conversion technologies is for heat and power generation. This conversion pathway offers the best route for carbon dioxide emission reduction since net CO_2 emission of biomass derived electricity or heat constitutes just 5% of the emissions of coal life cycle. With regard to constrains on land availability for energy crop production, the important issue is efficient resource utilization. Combined heat and power generation gives the most complex and efficient use of biomass and can significantly contribute to making bioelectricity more economically viable. Further reduction and higher electricity generation efficiency can be achieved from commercial gasification technologies.

In order to reach the 2010 target of reducing carbon dioxide emissions by 8% from the 1990 level, rapid reduction of fossil fuel use is required. Co-firing is a solution for the rapid expansion of biomass-derived power through existing coal-fired plants. Additionally, installation costs are much lower compared to other options of biomass to power applications like biomass dedicated boilers or IGCC. This gives possibility to reduce CO_2 emissions in energy sector quickly. Blending liquid biofuels into petrol and diesel fuel is a kind of co-firing. But the investments are necessary for production of some of these fuels; the time required may be long.

However, under a scenario of maximization of carbon emission reduction, biomass will be used as a solid fuel in power plants and will substitute coal, reserves of which in Europe are abundant. Thus, when contributing to CO_2 emission reduction, biomass in this way will not significantly affect security of energy supply.

Considering **security of energy supply**, priorities of biomass application should be changed towards production of biofuel for the transport sector in the light of EU decreasing oil extraction and increasing EU's oil import dependence. However, this biomass allocation option is not cost-effective in short term due to the high production costs of biofuels as the processing technologies for traditionally used crops (rape, sugar beet, cereals) are mature with low possibility to be improved; CO_2 abatement cost will be high. However, that process can happen due to development in biomass conversion technologies with the utilisation of cellulosic materials. Trying to reduce carbon emission by only automotive fuel substitution, Europe most likely will not be able to reach its target by 2010 because it will not be possible to introduce such a significant amount of liquid biofuels into the market in short term due to higher production cost of biofuel compared to fossil petrol and diesel.

Bioelectricity, as well as electricity from other renewable energy sources, requires legislative and financial support. Uptake of bioelectricity is vital for its development. Taxation of carbon emissions, GHGs emission trading can improve the economics of bioenergy production. Financial measures like aids, tax deduction and financial support would promote rather ambitious EU's targets regarding share of biomass in particular and renewables in general in energy generation. The very promising mechanism to help EU Member States to fulfil their obligations of renewable energy consumption is a combination of targeting with international renewable electricity trading. But no single factor is the major. Instead, the extent to which renewable energy is exploited is determined by cumulative effect of supportive measures.

There exist EU Directives with targets for renewable electricity and automotive fuels. With a carbon emission quota system, it is not difficult to create policy measures for efficient CO_2 emission reduction. However, it is much more difficult to implement policy measures to influence security of energy supply.

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Abbreviations

BMU	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMZ	German Federal Ministry for Economic Cooperation and Development
CAP	Common Agricultural Policy
CCT	Clean Coal Technologies
CHP	co-generation heat and power
DME	dymethylether
EPA	Environmental Protection Agency
ETBE	ethyltertio-butyl-ether
GHGs	greenhouse gases
kt	kilotonne
Mbbl	million barrels (of oil)
MSW	municipal solid waste
Mtoe	million tonnes of oil equivalents
NFFO	Non-Fossil Fuel Obligation
NREL	National Renewable Energy Laboratory
odt	oven dry tonnes
PV	photovoltaic
RCG	Reed canary grass
RDF	Refuse Derived Fuel
RPS	Renewables Portfolio Standards
tce	tonnes of coal equivalent
toe	tonnes of oil equivalent

Appendices

Appendix 1 Countries-the largest biofuel producers in Europe

Table 7. Top list of biofuel producing countries in Europe (data for year 2002).

Country	Production capacity, ton/year and toe/year			
	biodiesel		bioethanol	ETBE
	ton/year	toe/year	ton/year	ton/year
Austria	30 000	27 000		
Denmark	10 000	9 000		
France	350 000	315 000	90 500	192 500
Germany	550 000	495 000		
Italy	220 000	198 000		
Spain	6 000	5 400	176 700	375 500
Sweden	10 000	9 000	50 000	0
Total	**1 176 000**	**1 058 400**	**317 200**	**568 000**

Source: EurObserv'ER (2003).

Appendix 2 Energy crops cultivated in Europe

Table 8. Energy crop species currently used or perspective to be used in energy or fuel production in Europe.

Latin name	Common English name	Hectares
	Woody crops	
Salix sp.	Willow	18,000
Eucaliptus sp.	Eucalyptus	500,000
Populus sp.	Poplar	4050
	Herbaceous crops	
Triticum aestivum	Winter wheat (GWC)	
Secale cereale	Winter rye (GWC)	
Triticale	Triticale (GWC)	
Hordeum vulgare	Spring barley (GWC)	
	Total for GWC (Grain Whole Crop)	9,400
Phalaris arundinacea	Reed Canary Grass	6250
Sorghum bicolor	Sweet Sorghum	50
Cannabis sativa	Hemp	550
Miscanthus sp.	Miscanthus	350
Cynara cardunculus	Cardoon	65
	Oily crops and crops for fermentation	
Brassica sp.	Rape seed	800,000
Helianthus annuus	Sunflower	91,000
Beta vulgaris	Sugar beet	9400

Source: (Venendaal, et al., 1997).

Appendix 3 Elements affecting the choice of crops for ethanol production

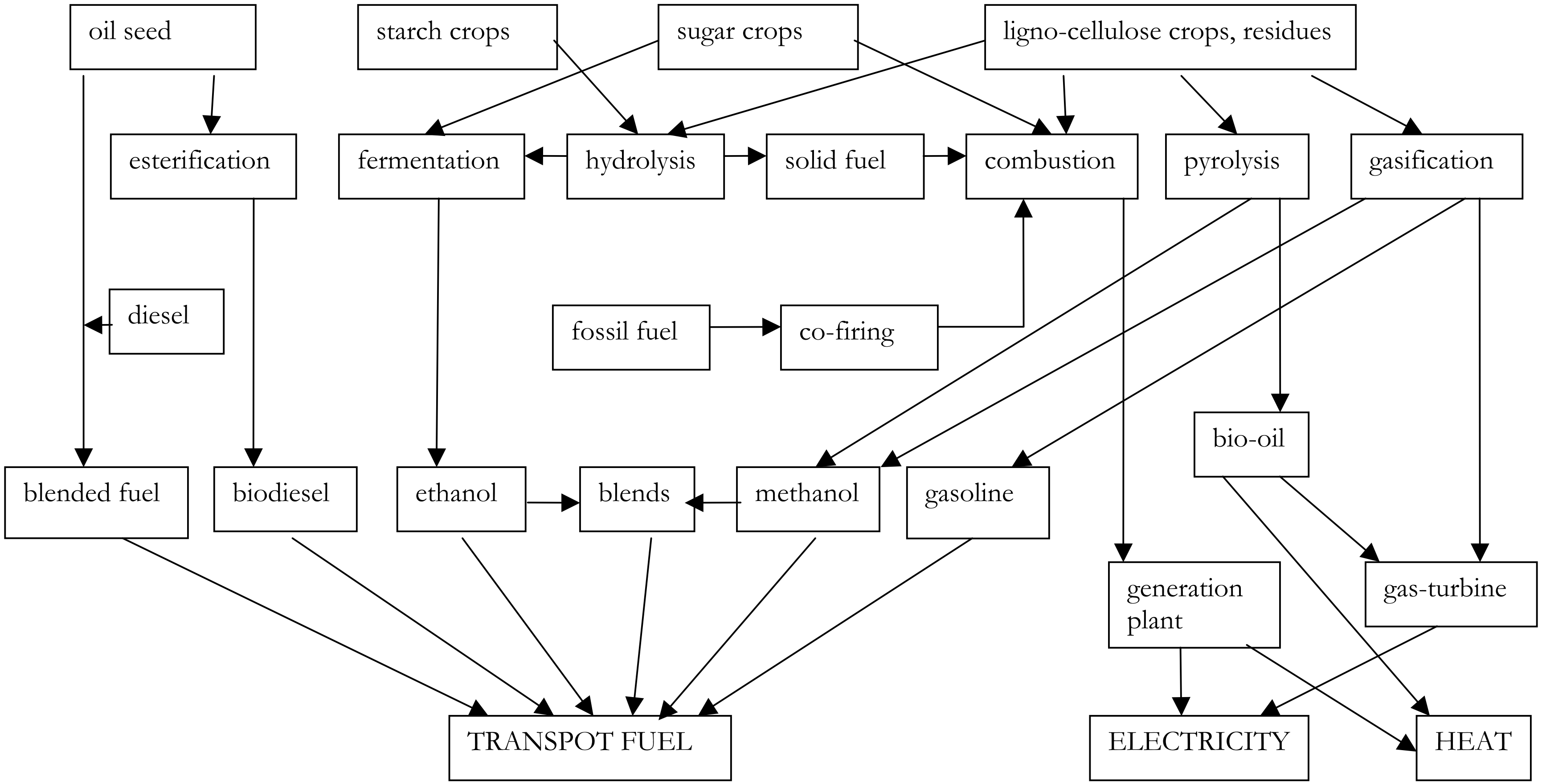
Table 9. Factors that influence the choice of crops for ethanol production.

Evaluated aspects	Wheat	Barley	Sugar beet	Sweet sorghum
Adaptability to the environment	High	High	Poor	Poor
Presence in the rotation	Wide spread	Wide spread	Wide spread	Not-existent
Introduction in new rotations	Easy	Easy	With limits	Difficult
Technical know-how	Very good	Very good	Very good	Difficult
Technical needs	Medium	Poor	High	Medium
Germplasm availability	High	High	Good	Low
Parasites control	Easy	Easy	Difficult	Easy
Special mechanization	Available	Available	Available	Prototypes
Transport cost	Low	Low	High	High
Conservation	High	High	Poor	Low
Industry supply	Constant	Constant	Unconstant	Unconstant
Future yield gain	High	Good	Medium	Difficult

Source: (Venturi and Venturi, 2003).

Appendix 4 Conversion routes for biomass

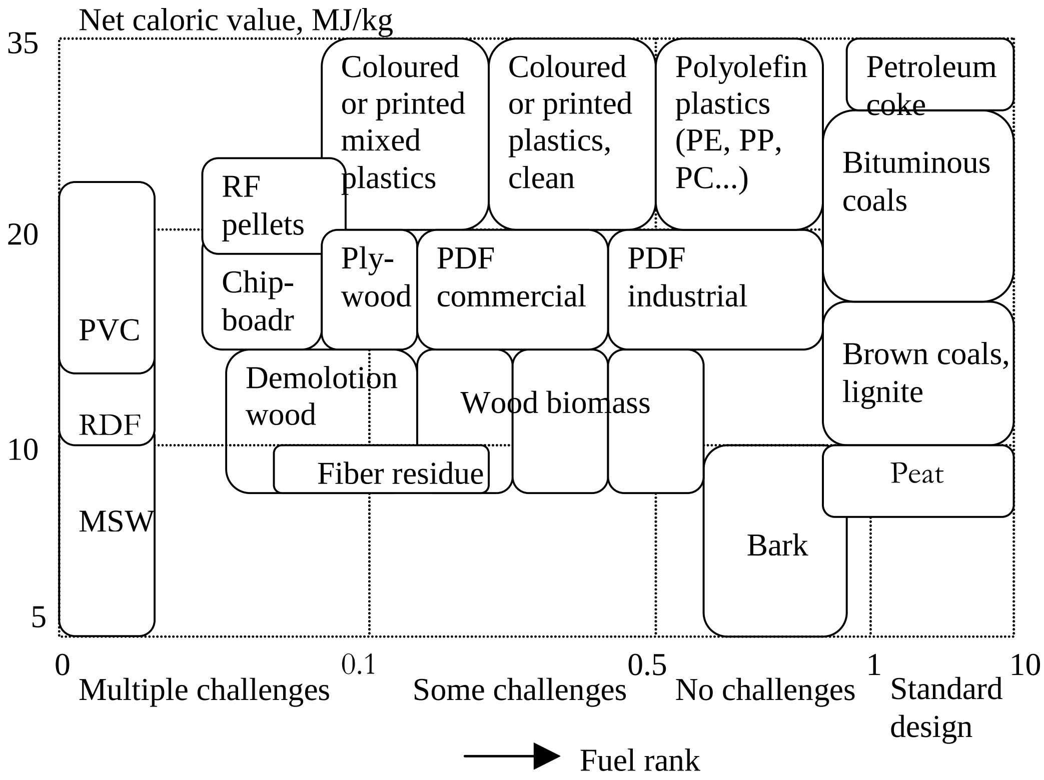
Figure 5.Conversion routes for energy crops.



Source: IEA CADDET (1998)

Appendix 5 Influence of fuel characteristics on boiler design

Figure 6.Influence of fuel type on boiler design.



Source: (EuBioNet, 2003a).

Appendix 6 Mechanisms promoting bioelectricity in Europe

Table 10 Policies and support mechanisms for bioelectricity in selected EU countries

OECD Country	General policy	Price support / market mechanisms	Subsidies, loans and tax measures
Austria	Fully liberalized market since October 2001. Renewable electricity mandate on distribution network operators (DNOs). Penalty to "green energy fund" if renewable electricity not cheaper.	Feed-in price support varies for different Länder and range between 0.028-0.04 €/kWh.	Federal program covers 30% of eligible investment costs. Länder have additional programs.
Denmark	Fully liberalized electricity market planned for 2003. Green certificate system planned for 2003.	Utility buy-back rate for renewable electricity of 85% of consumer price (average 0.043 €cents/kWh).	Additional support from CO_2 tax reimbursement. Investment subsidies up to 30% of investment.
Finland	Liberalisation ongoing. Grid opened to all producers at fixed transmission cost. National action plan for renewables focused on biomass in near term. 10 Regional energy management agencies.	Wood fuel derived electricity receives subsidy.	Investment subsidies up to 30% of investment. Bioelectricity is exempt from the electricity tax and allocated a tax relief rate of 0.3 €cents/kWh.
Germany	Fully liberalized market since 1998. Mechanisms being introduced to encourage CHP grid connection.	20 year fixed feed-in price for renewable electricity. Bioelectricity prices: 10.2 €cents/kWh <500 kW, 9.2 €cents/kWh 500kW-5MW, 8.7 €cents/kWh >5MW. 1% annual decrease 2002+.	Market Incentive Program provides 20% investment subsidy on average. Efficient CHP is exempted from ecotax.
Italy	Electricity market liberalised for large energy consumers. Renewable electricity prioritised for remote grids. Renewable electricity obligation of 2% new renewable electricity by 2002 (based on 1997 levels) and expected to increase in line with White Paper.	Green certificate market. Average price of green certificates estimated at 5.5 €cents/kWh.	
Sweden	Liberalisation ongoing. Renewable electricity obligation and green certificate introduction in 2003.	Temporary support of 0.9 €cents/kWh.	Investment grants of up to 25% or a maximum of €360/kW. Lower or no energy taxation for small-scale renewable electricity production. Sulphur taxation: biofuels exempt.
United Kingdom	Fully liberalized market. Renewable obligation from 2002 on electricity generators. Climate Change Levy (energy tax) on fossil and nuclear energy. Future Energy green electricity accreditation scheme for voluntary market. Gas and Electricity Regulator addressing distributed generation issues. Biomass co-combustion Incentives end 2006.	Renewable obligation certificates (ROCs) market to meet renewable obligation of 10% by 2010. Generator buy-out price of about €4.5/kWh.	Investment subsidies through The Carbon Trust in progress. Bioenergy Capital Grants scheme from the DTI/National Lottery/DEFRA aimed at biomass for energy and in particular establishment of energy crops. Enhanced capital allowances on investments in energy savings.

Source: Bauen, et al., (2004).