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Biomass in energy supply, especially in the state of Brandenburg, Germany

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Abstract

As a result of growing visible damage to the environment connected with the use of fossil fuels, biomass is increasingly becoming a topic in energy economical and political discussions. Also, the limitation of fossil fuels and the associated dependency on international energy markets make a change of view to the direction of an energy supply based on biomass increasingly necessary. Solid biomass from agriculture and forestry that is not used in industrial production, such as food production, as well as non-contaminated or even contaminated solid biogenic waste-products and residue that have to be reused after the new commercial and industrial waste management act, is suitable for energy production to cover the existing heat and power consumption of single projects, like swimming pools, schools, or even for municipalities. Against this background an analysis will be made of the technical possibilities of the application, ecological aspects, existing potential of biomass, and the economic viability of energy supply based on biomass, especially on wood. © 2000 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Heating plants; Co-generation plants; State of the art; CO_2-emissions; Comparison of biomass and hard coal; Economic use of biomass; Supply structure; Potential of biomass; Annuity of the capital value

1. Technical possibilities of application

In heating plants, biomass is fed to a chemical process in order to be converted into heat. During the combustion process heat is released by an exothermic reaction. The biomass is cut up and fed to the combustion chamber either by hand or by a conveyor belt. The heat produced in the process is transformed into low-temperature heat by a heat exchanger. Technically speaking, the combustion of solid biomass is well developed.

In principle, it is possible to burn solid biomass in plants of different sizes and with different consumer energies (Hein et al., 1994):

- small combustion plants in households with a capacity up to 15 kW that are run with typically full load times of 1500 h/a, and mainly used to produce hot water and room temperature;
- small combustion plants in industries and trade that have a thermal capacity between 15 kW and 1 MW and which sometimes also produce process steam. These plants usually run with a full load time of 1500 to 2000 h/a;

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- larger plants with a capacity of 1 to 10 MW that are mainly run at woodworking industries and that produce electricity in addition to heat and steam. Here, 3000 to 4000 full load times per year can be reached;
- biomass burned together with coal in coal-fired power plants. In this utilization the production of electricity is in the foreground with an operation time of approx. 7000 h/a. Between 10 and 100 MW of thermal capacity could be used here.

Combining the production of heat and power (KWK) can clearly increase the efficiency of the plants. There are two process principles. By using a turbine in a co-generation plant, power as well as low temperature heat can be produced. This process is not economic yet because of the high investment costs and is therefore not used in practice. Another process is found at district heating power stations where gas that is produced in a wood or straw gasifier is fed to an engine to produce electricity. The waste heat can be used to produce low-heat temperature. This process is still in the development phase. There are problems, especially with the production of a clean wood or straw gas with a high thermal value, and with the combustion of gas engines that are not easily adapted to the quality of gas.

Also, rapeseed oil or rapeseed oil methyl ester (RME) are suitable to be used in district heating power stations (BHKW). Rapeseed oil can be used instead of heating oil and thereby indirectly as diesel oil. Special engines are necessary to use these fuels. RME however, can be used in conventional diesel engines without any adaption. RME can be used as a substitute for diesel oil. The different processes are shown in Fig. 1.

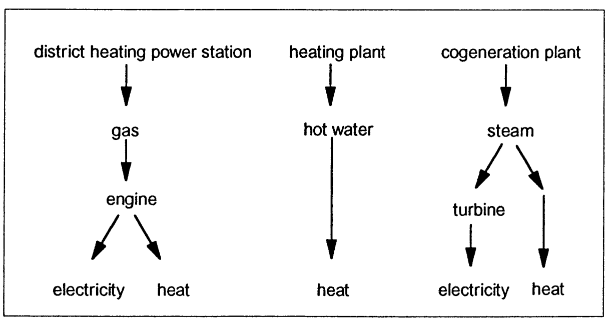

Fig. 1. Process principle of producing heat and electricity.

Besides the higher fuel utilization compared to heating plants, the processes of KWK are more economical because of the increase of income caused by the additional sale of electricity. On the other hand, local and long-distant heating networks have to be constructed, which, in the FRG, are only economically viable beyond a heat load density of 25 to 60 MW/Km^2 (Mebold and Marschallek, 1988; Tietz, 1983; Voß and Nitsch, 1987).

A study by the Institut für angewandte Ökologie e. V. showed that in Brandenburg there would be an economic power heat linkage potential of 379 MW_{el} if public utilities implemented power heat linkage plants; the only peripheral condition is that they are credited for all work and performance costs that they avoid (Matthes et al., 1994).

The economic viability of heating plants increases with an increasing capacity caused by decreasing investment and operation costs. A further increase of the economic viability can be reached by an increase of production because, with increasing number of units, the production costs can be reduced.

In Brandenburg the number of wood-fired plants is increasing continually. Since 1991 at least 462 modern wood-fired plants have been installed and put into operation (Scholz et al., 1997) (Fig. 2). Numerically, small chopped wood boilers with a capacity of 10 to 50 kW predominate. However, looking at the total capacity, large-scale plants up to 500 kW are producing with more than 80% a far higher share.

2. Ecologically relevant aspects of the energetic use of biomass

The initial idea of returning to biomass for energy production was the goal for substituting limited fossil fuels. In recent years, however, the trend has additionally been to reduce the emissions of CO_2. In 1991 Germany decided to reduce the CO_2 emissions to a level 25–30% less than CO_2 emission levels from 1987 by the year 2005;

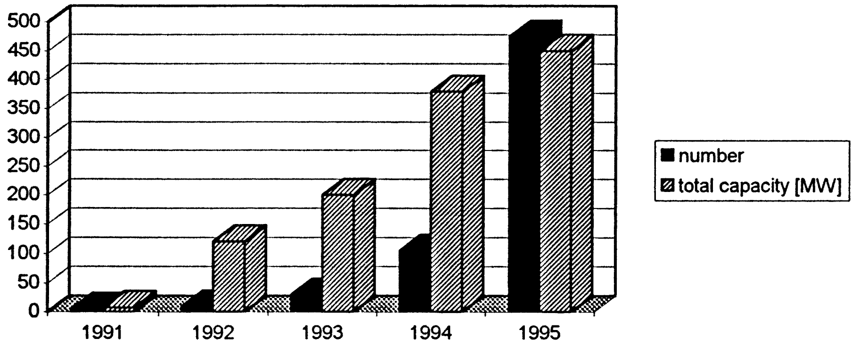

Fig. 2. Increase in the number of wood-fired plants in Brandenburg since 1991 (Scholz et al., 1997).

this goal is still being followed after the conference in Kyoto (Presse- und Informationsamt der Bundesregierung, 1998).

The use of biomass is regarded as CO_2 neutral because CO_2 emissions arising at the combustion process have been absorbed before the growth of the plants. The CO_2 emissions that affect the environment, arise at the biomass supply, which means at the harvesting, the transportation, the reprocessing, and the waste disposal of ash or slag. The CO_2 circle is shown in Fig. 3.

Therefore, it can be said that in substituting fossil fuels with biogenic fuels there is a CO_2 reduction potential of 53.0 million tons per year in Germany (Table 1), whereby the use of wood would make up the largest part (Hartmann, 1994).

Besides the CO_2 emissions, other products of waste gas produced at the combustion process have an influence on the environment. There are NO_x, SO_2, CO, as well as dust and soot. Among other things, these are dependent on the size of plants as shown in Fig. 4.

An evaluation of biomass in comparison to hard coal shows that wood can be evaluated as the best fuel and therefore its use in energy supply should be promoted (Table 2). For rapeseed oil and RME, which are evaluated in comparison to diesel oil, it turns out that rapeseed oil equals + 6 points and RME + 13 points, which means that these are far better than their reference fuel.

Today, the damages caused by CO_2 emissions

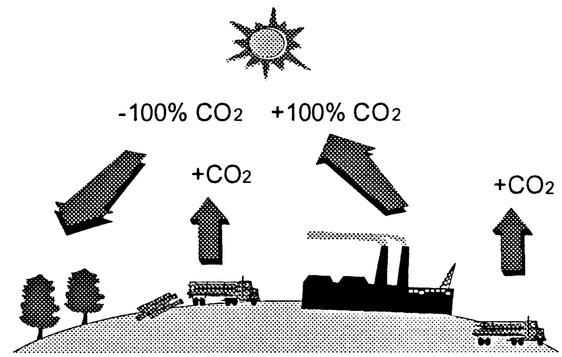

Fig. 3. CO_2 emissions produced at the energy supply based on biomass.

Table 1
Net CO_2 reduction potential in Germany using biomass fuels (Hartmann, 1994)

Process/raw material	Net CO_2-reduction potential[a]	
	Million tons per year	% Of total emissions [b]
Energy plants	29.5	3.24
Straw	7.6	0.84
Wood (forest waste)	10.3	1.13
Wood (industrial waste)	5.3	0.58
Wood (land conservation waste)	0.3	0.03
Total	53.0	5.62

[a] Taking emissions caused during refinement into consideration.
[b] 910 million tons per year (1992, including the New Federal States).

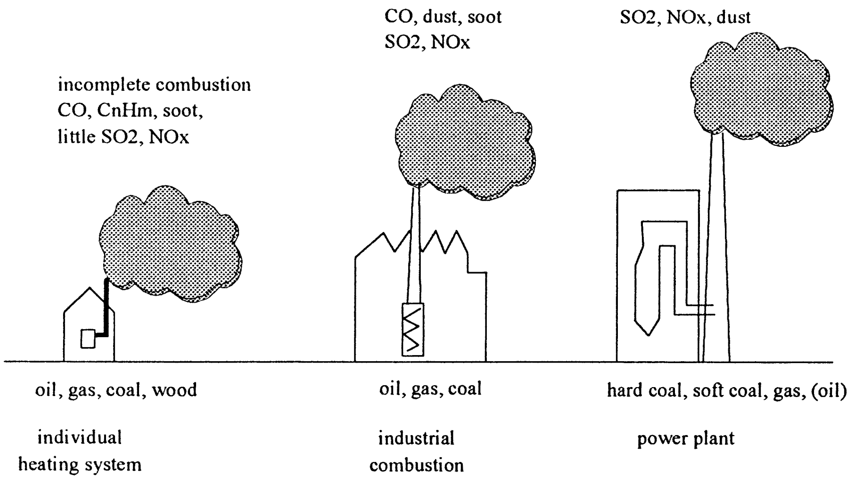

Fig. 4. Waste gas emissions at combustion plants of different sizes (Baumbach et al., 1994).

Table 2
Comparative evaluation of environmentally relevant aspects of the storage, reprocessing and use of biomass in comparison to hard coal (Hartmann and Strehler, 1995)

Judge main Processes	Criterion	Wood chips	Straw	Cereal plant	Miscanthus	Hay from landscaping
Storage	Fungal infection and storage loss	–	o	–	–	o
	Fire hazard	o	–	–	–	–
	Spontaneous combustion	o	o	o	o	–
Reprocessing	Dust input	+	o	o	o	o
Use	CO	o	–	–	–	–
(Emissions)	C_nH_m	o	–	–	–	–
	NO_x	+	+	–	o	o
	SO_2	++	+	+	+	+
	Dust	+	–	o	o	–
	CO_2	++	++	++	++	++
Use	Occur of ash (amount)	++	–	o	+	–
(Residue)	Ash disposal (in circle)	++[a] (o)	++	++	++	o (++)[b]
	Occur of slag	+	–	o	–	– –
Sum		+15	+1	+1	+2	−4

[a] Short rotation plantation.
[b] Better comparison without conservation restriction explanation: clear advantage (++); advantage (+), equal (o); disadvantage (−); clear disadvantage (− −).

can neither be evaluated nor attributed to the polluters. If in the future becomes possible and the damage costs are covered by the CO_2 polluters, a re-calculation of figures showing economic viability will improve the competitiveness of biogenic fuels.

3. Supply structure in Brandenburg

The supply of electricity in the former GDR was produced by the use of coal-fired electrical-power or thermal-power stations. In contrast to the Federal Republic of Germany, heating requirements were met in the main by centrally located long-distance heating systems or by coal-fired single- or multiple-room stoves. These supply structures are also typical for Brandenburg, where single- and multiple-room stoves supply heat to ≈30% of all dwellings (Landesamt für Datenverarbeitung und Statistik Brandenburg, 1996b). The various types of energy used to heat dwellings include coal (34%) — which is being extracted in the region, heating oil (14%) and wood or other energy resources (22%) (Landesamt für Datenverarbeitung und Statistik Brandenburg, 1996b). However, these supply structures cause numerous environmental problems because coal with its high carbon content produces large amounts of pollution, dust, and soot during combustion.

Since most heating systems are out-dated and will either have to be renewed or altered, the municipalities have the historically unique opportunity of renewing or re-organizing the heating supply (Ilum, 1995). This opportunity can be used to build up a heat supply based on renewable energy, with biomass offering the most possibilities for potential use.

4. Potential of biomass

With a solar radiation of ca. 1000 W/m^2 and an average duration of sunshine about 1200 h, there is a solar radiation of about 1200 kWh/m^2. Out of this, biogenic fuels can supply on the average the following solar energy contribution (Plank, 1994):

normal forest	15.7 MWh/ha/a
energy wood plantation extensive	45 MWh/ha/a
energy wood plantation intensive	90 MWh/ha/a
whole plant grain extensive	45 MWh/ha/a
whole plant grain intensive	90 MWh/ha/a
straw	13 MWh/ha/a
hay from landscaping	27 MWh/ha/a

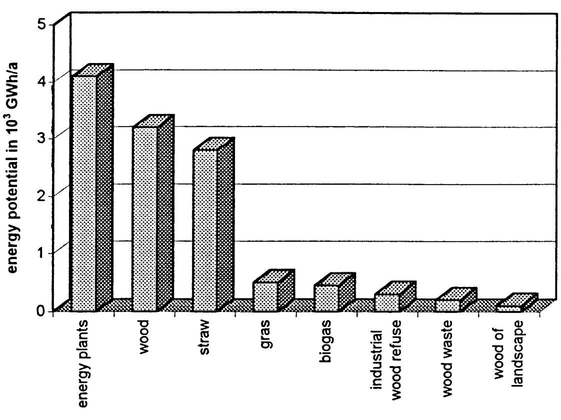

Fig. 5. Total potential of biogenic fuels in Brandenburg (Scholz et al., 1997).

If the energy potential of wood per inhabitant is taken into consideration, Brandenburg would be on the top of the list. Wood potential per person is 5.11 GJ/a and is therefore almost twice as high as in Bavaria (2.85 GJ/inhabitant a) (Cames and Matthes, 1994). The amount available from the forestry industry for energy purposes is ≈3 GWh (Scholz et al., 1997). Brandenburg has a large amount of softwood trees, of which 80% are pines. There is ≈10 973 GWh/a of residual materials left over from agriculture, such as straw, grass, and wood. The energy potential of these residual materials can be seen in Fig. 5. In 1993 it would have been possible to grow up to ≈150 000 ha of energy plants on rotational and long term fallow land, that were unused in accordance with an EU-land retirement program (Haschke et al., 1994).

The biomass potential shown in Fig. 5 could cover ≈16% of the total energy consumption of Brandenburg households, which in 1994 amounted to 247.64 PJ (Landesamt für Datenverarbeitung und Statistik Brandenburg, 1996a).

5. Economic field of applications

In order to examine the economic viability of different possibilities of energy supply, it is necessary to calculate the costs of industrial combustion plants, fuels, and with a supply based on centrally located heating stations or district heat-

Table 3
Conditions for an economic use of biomass for a municipality in Brandenburg[a]

Conditions	Prices/rates (DM/KWhHu)	Technology	Distribution of capacity (thermal) (%)	An(C) (TDM/a)
Actual costs		HW_G	75.7	480.1
		KWK_G	24.4	
pBio = 75%	Wood = 0.023	HW_UBio	92.4	467.8
		KWK_G	7.6	
pF = 120%	Natural gas = 0.04	HW_UBio	92.4	541.1
	plus 15.6 DM/kW	KWK_G	7.6	
EINB = 220%	0.0335	HW_G	75.4	478.19
		KWK_G	7.4	
		BHKW_Raps	17.2	
	(TDM)			
IBKWK = 75%		HW_G	74.2	477.8
	181.1	KWK_G	16.3	
	281.2	BHKW_Biogas	9.5	
IBHW = 45%	405.1	HW_uBio	69.6	475.9
		KWK_G	30.4	

[a] Explanation: pBio, price for wood; pF, price for natural gas, EINB, payment for electricity produced by biomass; IBKWK, state subsidies for biogenic-fired co-generation plants; IBHW, state subsidies for biogenic-fired heating plants; HW_uBio, biogenic-fired heating plant; KWK_G, gas-fired district heating power station; BHKW_Raps, rapeseed oil-fired district heating power station; KWK_Biogas, biogas-fired district heating power station.

ing power stations, the heat distribution costs. If only the costs are taken into consideration, it can be stated that the supply costs of biomass-fired plants are $\approx 20\%$ higher than those of individual heating stoves serving the whole community. An oil-based supply would, however, be the cheapest for a community of fewer than 200 inhabitants. For higher populated communities, a gas-based low temperature boiler would be cheaper. The same tendency can be seen when considering centrally located heating supplies. The network system costs are too high at this heat density. The combined generation of heat and power is more expensive using biomass-fired combustion plants than conventional plants, which moreover, are more cost-intensive than simple heating stations.

Different factors have an influence on the economic use of biomass. For example, investment costs of biomass-fired plants, fuel prices and payment of electricity produced out of biomass and fed into the public power supply system have to be named. The economic conditions for the use of biomass were analyzed for a typical rural municipality with 660 inhabitants and a structure of a linear village with a mixed-integer linear optimization model (Table 3). The examinations were based on the assumption that a district heating system already existed and they were carried out under the condition that the municipality joined together with an operating company. The dynamical evaluation of economic efficiency using the annuity of the capital value (An(C)) was employed. Electricity produced in a co-generation plant can be used in the farming industry and in this way the electricity that has not to be taken out of the public power supply system can be credited. If production exceeds the need, it can be fed into the public power supply system by payment.

The prices for biomass should be 75% of the actual price (0.03 DM/kWh_{Hu}) so that a biomass-fired heating plant together with a gas-fired district heating power station is economically viable. In this way the actual gas-fired heating plant is substituted. Or the fossil fuel prices have to be increased to 120% from 0.033 DM/kWh_{Hu} plus 13 DM/kW up to 0.4 DM/kWh_{Hu} plus 15.6 DM/kW in order to attain an energy supply based on a biomass-fired heating plant. Under these conditions the district heating power station has a lower thermal capacity in comparison to today's levels. The payment of electricity produced out of biomass fed into the public power supply system has to be increased to 220% (actual price: 15.25 Pf/kWh). Also, state subsidies for biomass-fired heating plants or co-generation plants help to improve the economic use of biomass and thereby to substitute fossil-fired plants. For heating plants, the state subsidies have to take 45% of the costs and for co-generation plants they have to take 75%. The results show that in district heating systems biomass can be used by changing the conditions.

6. Conclusion

Many different technologies are available to use biomass for heat and power or for combined heat and power production. Some of the processes are not yet mature, but the use of biomass is already possible. Economical problems exist because of the higher investment and operating costs in comparison to fossil-fired plants. Here, for example, state subsidies are necessary to improve the economic viability. Looking at the ecological effects of burning biogenic fuels, wood comes off very well. But the other types of biomass are less damaging to the environment than their reference fuels. Concerning CO_2 emissions, biomass can help reduce the emissions because the CO_2 arising at the combustion was admitted before the growth. Especially in Brandenburg, the potential of biomass that can be used for producing energy is very high. To improve the economy, the conditions have to be changed. This is possible by establishing taxes like CO_2 taxes or state subsidies for biomass-fired energy conversion plants or by changing the payment for electricity produced by biomass. In conclusion, there are many possibilities as well as restrictions in the use of biomass in the energy supply as shown in Fig. 6.

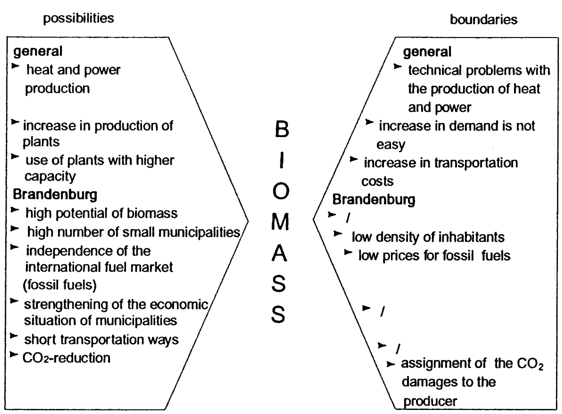

Fig. 6. Possibilities and boundaries of the economic use of biomass, especially in Brandenburg.

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