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Energetic utilisation of wood as biochemical energy carrier — A contribution to the utilisation of waste energy and landuse ☆

Oliver Bens, Reinhard F. Hüttl *

Chair of Soil Protection and Recultivation, Faculty of Environmental Sciences and Process Engineering, Brandenburg University of Technology, P.O. Box 10 13 44, D-03013 Cottbus, Germany

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Abstract — The aim of the ongoing research activities is to investigate options for biofuel production related to energy purposes. This is in accordance with the worldwide discussion — especially in industrial countries — on energy supply. The discussion became necessary because the use of raw energy carriers exceeds by far that of all the other raw materials. As a consequence, the amount of waste materials and waste products from energy plants, such as CO_2, exceeds by far that of all other plants. Moreover, there is a need for new sustainable landuse systems, especially in rural areas. This development coincides with efforts of the German government to enhance the production of biomass for energy purposes. In this context the goal is that a share of three per cent of the primary energy consumption should come from biomass. Wood from forest and field as a renewable resource may present an important alternative for heat and energy supply in rural landscapes, i.e. in areas with decentralised structures. Both a closed CO_2 balance and the protection of fossile energy resources achieved by the use of biomass meets current requirements of German policy. The state of Brandenburg offers the unique chance to adopt this strategy into reclamation activities on the large scale post-mining landscapes of the Lusatian lignite district and into changing landuse systems in rural areas. © 2001 Éditions scientifiques et médicales Elsevier SAS

biofuels / wood / CO_2 / lignite / reclamation / landuse systems

1. INTRODUCTION

Both the biggest consumption of resources as well as the biggest environmental burdens which are caused by the society are linked to power engineering and the material transforming processes related to it [1]. One example for this are the post-mining landscapes in the lignite mining area in Lower Lusatia [2–4]. Approximately 78 000 ha of land have been devastated here in connection with lignite mining. This land must be reproduced for future use by means of expensive recultivation measures. In connection with this we must develop sustainable concepts which allow, on the one hand, for a lasting environmentally friendly utilisation, on the other, a socio-economically viable use on the background of the EU framework conditions [5, 6].

Current studies are investigating the ends of transformation chains, i.e. the production of waste energy. The thermodynamic state of the flows of energy and material which are produced, i.e. their entropy, is an essential factor in assessing the interactions of landuse systems with their environment and the principal possibilities for shaping them. In contrast to energy, the conserved quantity, entropy allows us to draw conclusions as to which systems aim at a sustainable, environmentally friendly development. On the other hand, it shows clearly that a certain amount of waste energy that can be influenced is inevitable. The systems that are developed from this point of view are aiming at avoiding waste flows of energy and substance as far as possible or to recycle them for further use if they cannot be avoided.

During the past years the production of renewable resources, i.e. the production of growing raw materials (i.e. wood) for the primary purpose of energy production

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* Correspondence and reprints.

E-mail addresses: bens@tu-cottbus.de (O. Bens), huettl@tu-cottbus.de (R.F. Hüttl).

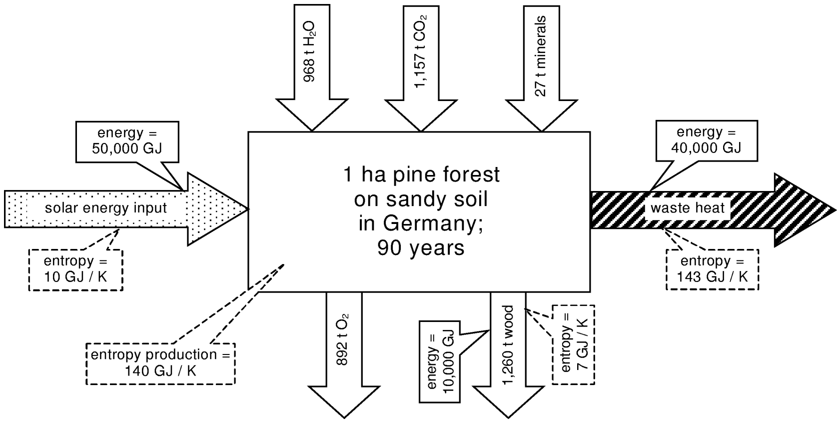

Figure 1. Gross balances for one hectare of pine forest on sandy soil in Germany that has been used for 90 years.

has been gaining more and more significance in Germany on the background of the limited resources of fossil energy carriers as well as of the potentially negative influence of CO_2 output in connection with the energy transformation and it is politically supported on the levels of the EU, the federal government and the states. The good provided in this process is among others the energy that is biochemically stored in the biomass as the product of sun irradiation and photosynthesis. Biomass is, thus, the only source of energy that can be stored nearly unlimitedly and that is renewable at the same time and which is, therefore, suitable for replacing fossil (limited) energy carriers to a relevant extent.

This energy carrier thus influences the entropy budget of the technological systems and it becomes comparable to other forms. Thus, we get the opportunity of expanding past considerations and show the influence of entropy imports exercised by the various energy carriers and approach as CO_2 load the environmental factors which play a role in the discussion on the assessment in addition to the energetic factors. *Figure 1* shows the material, energy and entropy balance at the example of a Scots pine forest. The indicated values refer only to photosynthesis and not to the entire sun irradiation reaching the area. This explains the relatively low values for the energy and entropy import and export.

Since 1996 the Berlin Brandenburg Academy of Sciences (BBAW) has been studying among other factors the contribution to the utilisation of waste energy and to entropy management made by the increased use of biogenic energy carriers in future energy supply. In this context waste energy is considered to be the utilisation of produced energy (in this case stored biochemically in wood). This includes not only wood that is produced without being energetically utilised to date but also wood that has been grown particularly for energetic utilisation. The study takes into consideration forestry, agriculture, maintenance of landscapes and also alternative landuse systems like short rotation plantations.

2. OBJECTIVES OF ENVIRONMENTAL POLICY AND AVOIDING WASTE ENERGY

Energy is always devaluated by transformation and dissipation processes and finally all energy is put out into the environment. This includes wood, too, when it is not used as material and whose biochemically stored energy remains unused. Avoiding waste energy and utilising it helps preserving limited (fossil) resources and protecting the living environment. With respect to the substitution of limited by renewable energy carriers bioenergy carriers bear essential significance. This is expressed in objectives of environmental policy consisting in developing energy supply and landuse systems that are sustainable in future.

In its green paper “Energy for the future: renewable energy carriers” (KOM(95)576) the European Commission formulates the objective of doubling the share of renewable energy carriers in the total gross national consumption of the EU from nearly 6 % in 1995 to 12 % in 2012. The European Parliament is striving for an even more ambitious objective with its demand for reaching a share of renewable energy carriers of 15 %. For Germany the Federal Ministry of Environment, Nature Conservation and Nuclear Safety [7] specifies this objective: the share is to be increased by the year 2010 to 4 % of the primary energy consumption and 10 % of power generation and then gradually to 50 % of the primary energy

TABLE I
The role of biomass in future global energy use [GWh]. For further details of references see [8].

Scenario	Year		
	2025	2050	2100
Shell (1996)	23 630	55 600–61 160	?
IPCC (1996)	20 020	77 840	88 460
Greenpeace (1993)	31 700	50 320	?
Johansson et al. (1993)	40 130	52 270	?
World Energy Council (1993)	16 400	26 130–43 650	36 700–59 770
Dessus et al. (1992)	37 530	?	?
Lashof and Tirpark (1991)	36 140	59 770	?

consumption in 2050. These objectives coincide with the more recent forecasts on the worldwide significance of biomass in future energy supply (*table I*).

The present political objectives give high priority to the objective of increasing the utilisation of biomass as fuel for producing thermal energy. In Germany activities are focussed on the following specific objectives with respect to quality and actions to be achieved by the thermal utilisation of biomass [7–9]:

- minimising the CO_2 output produced by energy transformation by means of increasing the use of biomass (in particular, wood) and reducing the use of fossil energy carriers,
- promoting the production of biomass for thermal utilisation as alternative form of landuse for securing a future basis of existence in rural areas and
- promoting only the production of types of biomass whose utilisation is ecologically and energetically reasonable.

The individual federal states are specifying this objective for their conditions. The state of Brandenburg, for instance, wants to increase the share of biogenic solid fuel in energy supply to 3 % by 2010. Wood is to be the main biochemical energy carrier [10]. In contrast to this objective of environmental policy the present share of energetically utilised wood is only 1.3 % [10] which means that there remains an enormous potential for growth which which is influenced by regionally differing framework conditions. However, an essential precondition for the energetic utilisation of biomass is to be able to supply the right amount, the right things (e.g., wood chips, saw dust) to the right place at the right time in the right (constant) quality and for the right prices.

3. SUPPLY OF WOOD AS CARRIER OF BIOENERGY

At the present state of the incineration, gasification and pyrolysis technologies biofuels can be energetically used as solid, liquid and gasified fuels. In general, the utilisation of biogenic fuels is only reasonable if the treatment, refinery and logistics of the basic materials are not energy intensive. Therefore, the utilisation of biomass which must be treated before thermal utilisation by energy intensive processes (e.g., thermal or mechanical drying, screening, purification) is almost entirely excluded from the point of view of energy, economic and environmental policies.

Solid fuels which are rich in energy are best suited as efficient energy carriers for thermal utilisation because:

- high specific yields per hectare can be produced,
- the energy input for cultivation/production, refinery and supply is relatively low and
- the energy balance is more favourable than for the utilisation of parts of plants, liquefaction or gasification of parts of plants.

In principle, it is possible, too, to produce heat and power from vegetable oils and gases. However, since only small parts of the plants are used in these cases profitability and the energy balance are usually less favourable than in case of the utilisation of whole plants. From among the biofuels solid fuels (straw, hay, wood chips) are more favourable with respect to efficiency and environmental friendliness than liquid or gaseous fuels since the former require a lower energy input in comparison to the net energy yield per hectare for production and refinery. When considering the solid fuels alone applies the rule that the lower the energy input for production and refinery (e.g., for compaction or pelletising) the higher the energy yield. Therefore,

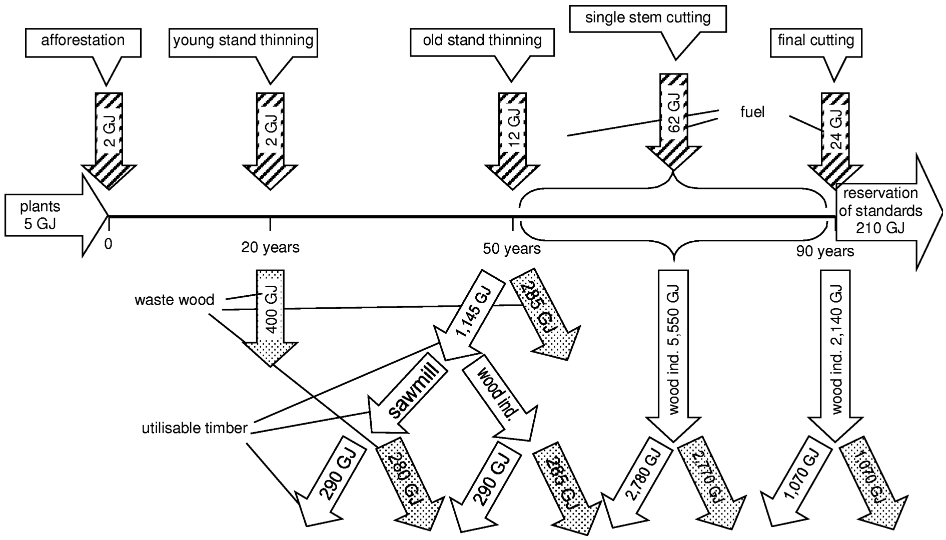

Figure 2. Energetic expense, benefit and energetically usable waste wood at the example of one hectare of pine forest on sandy soil in Brandenburg.

woodfuels (in particular, wood chips) have the most favourable energy balance.

Germany produces annually approximately 70 million tons of organic dry substance with an energy content of approximately 366 300 GWh. Only a very small proportion of this can be used technically. If you take into consideration the total efficiencies of the transformation techniques the (theoretical and maximum) usable energy potential is reduced to approximately 211 640 GWh per year [11]. How much of this potential is actually used depends largely upon the profitability and the energetic efficiency (energy losses as well as energy consumption for transport, storage, treatment, etc.) of the biomass. The German Council of Environmental Advisors estimates that the reasonably usable potential of the residual and waste biomass amounts to approximately 48 840 GWh per year [11]. In addition to the utilisation of biogenic solid fuels that are produced anyway the production of plants for energy production on set-aside farmland bears major significance. At present approximately 1.6 million hectares of set-aside farmland might be used in the entire Federal Republic of Germany [12]. Depending upon the composition of the plants this would stand for a maximum potential of primary energy ranging between 24 420 and 97 680 GWh per year. This would cover 1–2 % of the consumption of primary energy in Germany and, thus, be the same amount as the reasonably usable potential of residual and waste biomass.

Worldwide the annual felling amounts at present to approximately 3.4 billion m^3. 1.9 billion m^3 of this are wood for energy. This is a share of more than 50 % [13]. The shares of the individual continents differ considerably. In Europe approximately 15 % are used as wood for energy. The share of wood for energy is lowest in Norway (approximately 8.3 %) and highest in France (23 %). In Germany approximately 10 % of felling is presently classified as wood for energy production. This means that in Germany wooden biomass has a share of 1.3 % in energy transformation.

The annual felling in Germany of approximately 35 million m^3 [14, 15] could be significantly increased with the purpose of energetic utilisation without violating the principles of sustainability since wood reserves are big and continue growing super-regionally. The principles of sustainability are rather violated by excessive wood reserves at individual locations as well as by the partial overaging of stands. Further, it is possible to use in particular the wood that results from logging residues, stand logging or landscape maintenance which is hardly suitable for material utilisation [13–17] and forests can be considered to be combined production systems (wood for material and energetic utilisation) more than before (*figure 2*).

This approach provides various opportunities. One of them is to intensify the legally binding measures for transforming growing stock from age class forests with a small variety of species and pure forest stands

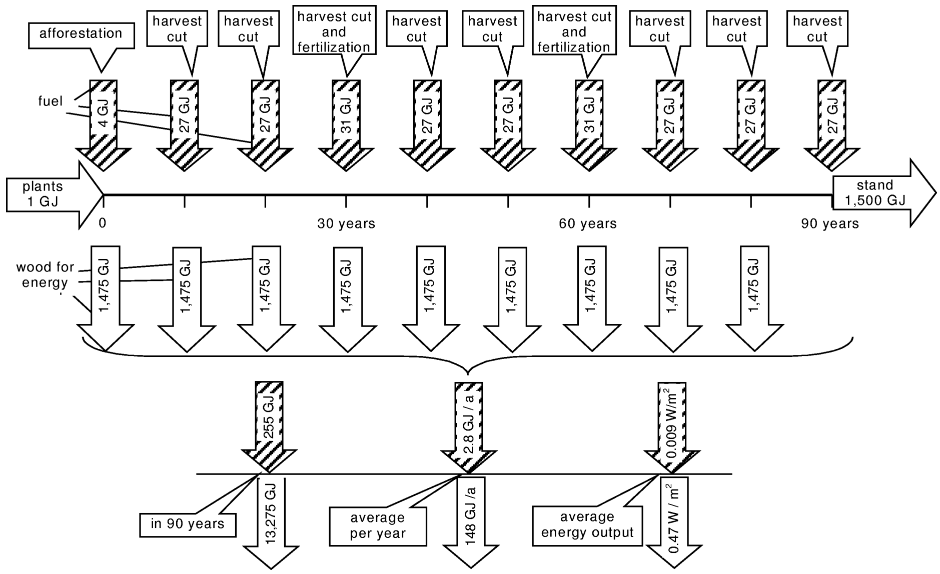

Figure 3. Energetic expense and supply of energy wood in a short rotation plantation (willow, poplar) on clayey sandy soil.

that are dominated by coniferous trees (e.g., in the northeast German low land where Scots pine dominate) into natural, stable forests that are suitable for their sites and to use low quality wood that is cut for waste energy utilisation.

Additionally, in particular rural areas with decentralised structures possess a high potential of bioenergy by growing so-called energy wood in short rotation plantations. Potential areas for growing these woodfuels are set-aside farmlands and recultivated land in post-mining landscapes [5, 6, 18].

The intentional production of wood for thermal utilisation is still in its initial stages, although small plantations with fast growing tree species have been operated for several years already on undisturbed soils and recultivated mine dumps [18, 19]. Forestry is calling those species of trees fast growing which produce at suitable sites a maximum average total growth of 10 to 12 solid measures of timber in m^3 (corresponding to 5.4 tons of dry substance) of wood per hectare and year. 75 % of this growth should be reached already at a low harvesting age [20]. Further, fast growing species should reach at fertile sites during a rotation period of five years an average dry substance output of at least 10 tons (i.e. 22 solid measures of timber in m^3) per hectare and year.

Growing fast growing tree species with short rotation periods is a transitional form between the two conventional forms of landuse — i.e. agriculture and forestry [21]. For the agriculture it means an extensification whereas for forestry it means an intensification of landuse. Depending upon the rotation period a difference is made between mini rotations (2–3 years), midi rotations (5–6 years) and so-called short rotation plantations with rotation periods of 10 to 20 years. High yields of biomass can be achieved mainly with certain species of balm poplars and their hybrids as well as with willows. On recultivated mine dumps in the Lusatian lignite mining area [18] were produced average yields of biomass of 2.5 (*Salix viminalis*) → 5.0 (Klon Rap) tons of dry substance per hectare and year. This means that short rotation plantations as alternative landuse systems may produce very high energy yields per hectare (*figure 3*). On former farmland the same plant species produced yields ranging between 5.6 and 25.0 tons of dry substance per hectare and year [22, 23]. We put this down to the fact that these soils have favourable conditions with respect to nutrients and moisture due to the long use as arable land.

We can summarize by saying that there is a big potential of land that may be used for growing biomass which consists of

- forests,
- arable land with utilisation of parts of plants from food production or utilisation of whole plants from non-food production,
- farmland that is set-aside according to the EU agricultural regulation,

TABLE II
Quality features of biogenic fuels and their effects (unaltered from [24]).

Quality feature	Most important effect
Chemical-material features:	
Water content	calorific value, storage life, mineralisation losses
Calorific value	fuel utilisation factor, design of equipment
Contents of chemical elements:	
Cl	emissions of HCl, dioxin/furan
N	emissions of NO_x, HCN and N_2O
S	emissions of SO_x
K	corrosion of surfaces of superheater, lowering the ash softening temperature
Mg, Ca, P	raising the ash softening temperature, influencing the binding of pollutants in the ash, utilisation of the ash
heavy metals	emission of pollutants, utilisation of the ash
Ash content	emission of particles, utilisation of residues
Ash softening temperature	safe operation of the equipment, level of emission of pollutants
Spores of moulds	health risks in fuel supply
Physical features:	
(Storage) density	expenses for storage and transport, expenses for logistics
Particle density/single density	burning properties (degassing rate, caloric conductibility)
Size distribution	safety of operation, drying, dust formation

- areas with lasting changes of utilisation (e.g., abandoned farmland with marginal yields) with following utilisation as short rotation plantations/energy forests and
- recultivated land after raw materials have been extracted (e.g., sand, gravel, lignite).

4. QUALITY FEATURES AND OPPORTUNITIES FOR OPTIMISING WOOD FOR ENERGY

The techniques that are relevant for growing, harvesting and refining biogenic solid fuels are known and well tested. However, the choice of certain methods and types of equipment influences to a certain degree the quality features of wood as energy carrier and may reduce undesired properties at least partially during production and refinery. Properties of solid fuels that influence quality are a number of factors and parameters which may be subdivided into the groups of chemical-material and physical properties (*table II*). The chemical-material properties comprise the contents of chemical elements (mainly chloride, nitrogen, sulphur, potassium, heavy metals) as well as the contents of ash, water and mould spores. They include also the calorific value and the ash softening temperature. In contrast to these the physical properties describe the visible features or correspondingly the refined form of the fuel (dimension, bulk density, particle density, fines content, abrasion resistance).

Efforts are made to minimise undesired and optimise desired quality features and minimise variations of quality as much as possible. The quality features may be influenced during the growth phase and afterwards during the supply, refinery and transportation (*table II*). During the growth phase can be influenced mainly the chemical-material properties in particular by the choice of the type of plant or cultivation, by choosing or breeding individual species (e.g., by breeding hybrid species), by choosing certain harvesting times as well as by using fertilizers and substances for treating the plants. Also the weather, the climate and in particular the soil properties exercise a significant influence on the substances contained in the plants and on the productive efficiency. Comprehensive corresponding knowledge has been gathered in classical agriculture or was elaborated during recent years for special site conditions [18]. Further, we should mention the types of influence that result from the forms in which agriculture and forestry are exercised in the individual regions (e.g., distance between rows, stand density, depth of sowing) and that may influence the quality of the solid fuel. During the second phase, the so-called supply phase, it is possible to influence mainly the physical properties. Harvesting methods, refinery methods as well as transport and storage may influence the quality.

TABLE III
Types of influence and their impact on the quality features of solid carriers of bioenergy (unaltered from [24]).

Type of influence/measure	Influenced quality feature	Mode of action/explanation
Growth phase:		
Choice of type of cultivation	K, Cl, N, S, ash, heavy metals, water content, calorific value	properties that are typical for individual species and chemical composition
Choice of species and breeding	K, Cl, N, heavy metals, water content	capacity for absorbing nutrients and pollutants, ripening behaviour
Climate (site)	K, Cl, N, water content	ripening behaviour, washing out of pollutants
Soil/deposition	K, Cl, N, S, heavy metals	availability of nutrients and pollutants
Time of harvest	N, K, Cl, heavy metals	washing out of pollutants, harvesting conditions
Age	N, ash, heavy metals	ratio wood/bark
Fertilisation	K, Cl, N, S, ash, heavy metals	availability of nutrients and pollutants, interaction with fertilisers
Supply phase:		
Harvesting method	water content, N, K, Cl, S, ash, physical properties	direct or phased harvest, separation grain/straw, method of comminution or compaction
Refinery	fines content	follow-up comminution, screening, pelletising or briquetting, additives, dewatering, technical leaching
Transport, handling	water content, mould spores	only for pellets and briquettes
Storage, drying		wet or dry preservation, weather protection, ventilation

5. CONCLUSION AND PROSPECTS

Wood as biochemical store of energy represents a specific form of waste energy which can be utilised by modern energy supply systems. When wood is produced as carrier of bioenergy either in conventional or in alternative landuse systems it offers the opportunity to provide major energy potentials for heat and electricity supply (*table IV*).

TABLE IV
Balance of the usable potential of waste energy from biogenic waste and bioenergy carriers (GWh per year). Data from [10].

	Germany	State of Brandenburg
Wood logging residues	39 476	2 860
Landscape managing wood	1 112	65
Industrial wood residues and old growth	20 016	526
Energy plants	119 540	4 085
Straw (plant residues)	30 024	2 003
Biogas	22 518	662
Others	?	662
Sum	232 686	11 000
Share of total need [%]	8.5	12

This applies in particular for areas with decentralised structures where even regional disparities may be balanced. Supply is guarantied and specific qualities which are adapted to the requirements of modern incineration/gasification equipment can be produced specifically for individual users. This can make major contributions to reaching objectives of energy policy.

Further, alternative forms of landuse (e.g., short rotation plantations) allow for establishing a lastingly environmentally friendly landuse in addition to improving socio-economic and cultural welfare without competing with traditional agriculture and forestry. Forestry will be able to use the forests in future more than now as integrated production systems for wood (for both timber and energetic utilisation). The state of technology allows providing the right amounts, the right products (e.g., wood chips, saw dust) to the right place at the right time and in the right (constant) quality.

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