ENERGY FROM BIOMASS:
Technology, Economy and Environment

Josef Spitzer
Joanneum Research, Elisabethstrasse 5, A-8010 Graz/Austria

Summary

Biofuel utilisation systems considered today range from simple stoves and furnaces to complex plants for combined heat and power production and for liquid biofuels production. Heat supply systems have been developed to an economically competitive stage while systems for electricity and transportation fuel production today are operated as prototypes only and still have to be further developed. Standard emissions from biomass combustion systems have been reduced to an environmentally acceptable level. Bioenergy is considered carbon neutral and is therefore reducing greenhouse gas emissions when substituting for fossil energy.

Biofuels and bioenergy potential

Solid, liquid and gaseous fuels derived from biomass are available today for use in energy conversion systems like furnaces, combustion engines and turbines. Both feed stock collection and fuel production technologies have been developed such that biofuels are competitive to fossil fuels in many applications. The global energy potential stored annually in the biosphere through photosynthesis and the main properties of biomass compared to fossil fuels are shown in Table 1. These numbers indicate that a major part of the fossil fuels used today may be replaced by biofuels and that biomass feed stock for the production of biofuels has a slightly lower energy content than coal or lignite. Typical examples of solid fuels for manual (logs and briquettes) and automatic (chips and pellets) feeding are shown in Figures 1 and 2. These fuels are successfully used to produce heat and power in small and large scale combustion plants. The processes for the production of liquid and gaseous fuels from biomass are basically known but are so far economical in special cases only: thermal gasification of solid biomass, anaerobic digestion of liquid waste biomass, biodiesel from vegetable oil, ethanol from grain, sugar bearing crops, and lignocellulosics and bio-oil from fast pyrolysis of lignocellulosics.

The contribution bioenergy is expected to make to meeting the global energy demand has been estimated by many authors. Table 2 shows examples ranging from 59 EJ/a to 149 EJ/a in the year 2025 with a further increase thereafter. The current contribution of bioenergy to the total world energy consumption of 406 EJ/a (1997) is estimated to be approximately 50 EJ/a. The main uncertainty of these estimates results from the non-commercial use of fire wood in third world countries.

Tab. 1: Basic data on bioenergy

Global potential (EJ/a)		
-	Energy equivalent of carbon stored globally through photosynthesis (50Gt/a)	1900
-	World fossil fuel consumption 1997	321
Calorific value (MJ/kg)		
-	Biomass (0% water)	17 – 20
-	Biomass (20% water)	13 – 15
-	Biomass (60% water)	5 – 7
-	Coal	25 – 30
-	Lignite	12 - 15

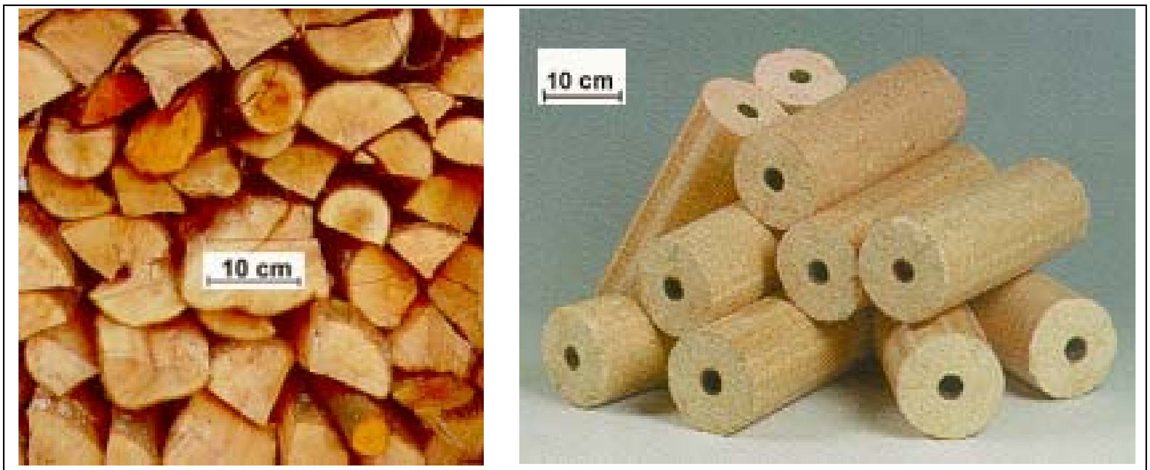

Fig. 1: Wood logs and wood briquettes as biofuel

Fig. 2: Wood chips and wood pellets as biofuel

Tab. 2: Current use and future potential of bioenergy

Current use: 50 EJ/a of 406 EJ/a total world energy consumption

Future potential (EJ/a):

Scenario	2025	Year 2050	2100
Shell (1996)	85	200-220	-
IPCC (1996)	72	280	320
Greenpeace (1993)	114	181	-
Johansson et al (1993)	145	206	-
WEC (1993)	59	94-157	132-215
Dessus et al. (1992)	135	-	-
Lashof and Tirpak (1991)	130	215	-

Source: D. O. Hall and J. I. Scrase (1998), Biomass & Bioenergy 15 (4/5), pp.357-367

Small scale heat production

Stoves and residential boilers operated with wood chips, wood pellets and wood logs have been optimised in recent years with respect to efficiency and emissions. Figure 3 shows a typical wood log stove (left) and an automatically fed pellet boiler (right). Further improvements regarding fuel handling, automatic control and maintenance requirements are necessary. Particularly in rural areas there is a great potential for the application of these systems.

Fig. 3: Wood log furnace (left, Rika/Austria) and automatic wood pellet boiler (right, Herz/Austria)

District heat systems

Municipal district heat plants, operated by farmers co-operatives or industrial enterprises, e.g. wood processing or pulp and paper companies, supplying also district heat, typically have a power level ranging from 0.5 MW up to 20 MW. Special boilers for these systems have been developed in recent years (Figure 4). Automatic fuel feeding, control systems and particle filters assure environmentally acceptable operation meeting the required emission limits. To improve efficiency and further reduce particle emissions some plants are equipped with flue gas condensing systems. In Austria such district heat systems have been built since the early 1980s, today approximately 400 units are in operation. Figure 5 (left) shows the heating station of such a system.

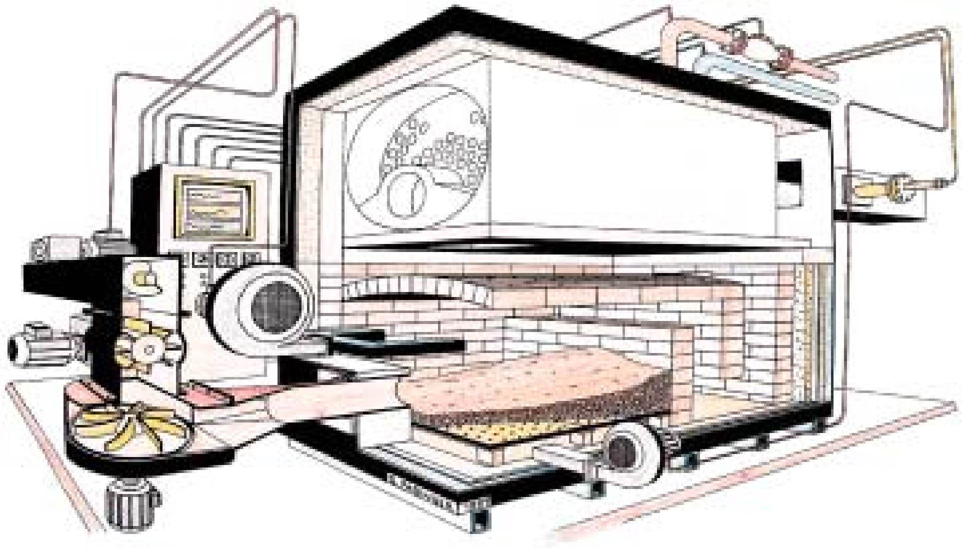

Fig. 4: Wood chip heat boiler 0,3 – 3,0 MW (LBH/Austria)

Fig. 5: Biomass district heat plant at Passail, Austria (left); Steam CHP plant at Reutte, Austria (right)

Combined heat and power plants

To increase the share of bioenergy in the energy market biofuels have to be introduced in electricity production. Due to the low energy density of solid biofuels the cost of transportation and storage are higher compared to fossil fuels. To limit these costs biomass power plants generally will be smaller than fossil power plants, typically in the range below 30 MW_{el}. This increases the opportunity to operate them as combined heat and power (CHP) plants to cover the district heat demand of small communities. On the other hand, the standard steam cycle technology is not economical in the lower power range. Therefore R&D efforts are under way to develop special systems for biomass fuelled CHP plants.

<u>Combustion:</u> Steam cycle plants with turbines or piston engines are available and are in operation in the power range above 5 MW_{el}. Figure 5 (right) shows a typical steam CHP plant operated by a wood processing company using residues from both manufacturing and near by logging operations: 6,3 MW process and district heat, 1,3 MW electricity. R&D projects for systems using the combustion gas directly for power production, thus avoiding the high operational cost of steam cycles, are carried out with some success. An example is a Stirling engine whose heat exchanger is placed in a duct between the furnace and the boiler of a heating plant (Figure 6, left). The goal of this development is an engine that covers the electricity demand of a district heat plant for fuel handling and pumping. A number of other concepts are under development, e.g. the hot air gas turbine system, the application of power units using the organic Rankine cycle and biomass co-combustion in coal fired power stations.

Fig. 6: 3 kW Stirling engine for biofuel operation at JOANNEUM RESEARCH, Austria (left); flash pyrolysis plant at VTT, Finland (right)

<u>Gasification:</u> Two main concepts are under development, one aiming at the use of the product gas in a combustion engine in the power range up to a few MW_{el}, the other at the use in a combined gas turbine and steam turbine system in the higher power range (integrated gasification combined cycle, IGCC). Figure 7 shows a successful IGCC prototype plant with an electrical output of 10 MW. The main problem yet to be solved in these developments is a low cost gasification process yielding a clean product gas with a high heating value. An overview of the international development in this area is presented in the Annual Report 1999 of IEA Bioenergy (IEA 1999).

Fig. 7: Integrated gasification CHP plant in Värnamo, Sweden

Liquid Fuels for Transportation and Power Production

Liquid fuels may be produced from biomass through biological and thermochemical processes. Biodiesel from rape seed oil or used frying oil is used in standard Diesel vehicles with minor modifications. However its potential to replace fossil Diesel is limited because the limited availability of feedstock. Ethanol from sugar and starch plants is widely used where economic incentives are available. Ethanol from lignocellulosic material has a big potential to replace fossil transportation fuels on a large scale, however the technology has to be developed further from the prototype plants in operation today. Bio-oil, the product of fast pyrolysis of biomass (flash pyrolysis), has a potential for both heat and power production. While the production technology is basically developed, the properties of the fuel has to be improved for standard application in boilers or stationary engines for power production. Figure 6 (right) shows a flash pyrolysis prototype plant.

Economy

As indicated in the previous sections today bioenergy is competitive with fossil energy systems only in few applications, mainly in small scale heat supply systems. The reason for this lies in both higher fuel production cost and higher end use conversion cost. Table 3 shows the cost of small scale heat production with wood log, wood chip and wood pellet heating systems at different power output levels. These cost should be compared to the cost of boilers using fossil oil and gas. Wood log boilers and medium size wood chip boilers are competitive at fossil fuel prices as of summer 2000. With increasing fossil fuel prices the more advanced pellet systems will be competitive as well. It cannot be expected that the cost of bioenergy systems will decrease to the extent necessary to achieve competitiveness of all applications expected to be implemented. Thus a breakthrough of bioenergy can only be expected if the cost of fossil fuels increases, either due to world market development or due to fiscal measures (fossil fuel taxes, subsidies for bioenergy systems) in individual countries. Figure 8 (upper part) shows how an increase of energy prices (cost/MJ) will lead to the implementation of both energy efficiency measures and the use of renewable (carbon-neutral) energy sources: with increasing cost these options become more and more economical thus covering an increasing fraction of the energy demand. Fiscal measures to increase the cost may be justified through a number of positive secondary effects associated with the use of renewable energy sources in general and bioenergy systems in particular. An analysis of the external effects of fossil fuel utilisation compared to the use of renewable energy sources indicates that an internalisation of external cost would offset the present cost advantage of fossil fuel systems. In the case of bioenergy a major positive effect is seen in the new opportunities offered to agriculture in the production of biomass for energy use and to local enterprises in the construction and operation of bioenergy systems. However, such analyses contain large uncertainties (in particular related to the cost of global warming) so that a basis for the necessary political actions is not yet available.

Tab. 3: Average cost of heat from biomass and fossil fuels (prices of summer 2000)

Wood log furnaces	Euro/kWh
- Cheminees	0,139
- Wood log boilers	0,068
- Tiled Stoves	0,239
Wood chip boilers	
- 15 kW	0,100
- 30 kW	0,089
- 100 kW	0,054
Wood pellet boilers	
- 15 kW	0,120
- 25 kW	0,110
- 45 kW	0,103
Fossil fuel boilers	
- Fuel oil	0,105
- Natural gas	0,100

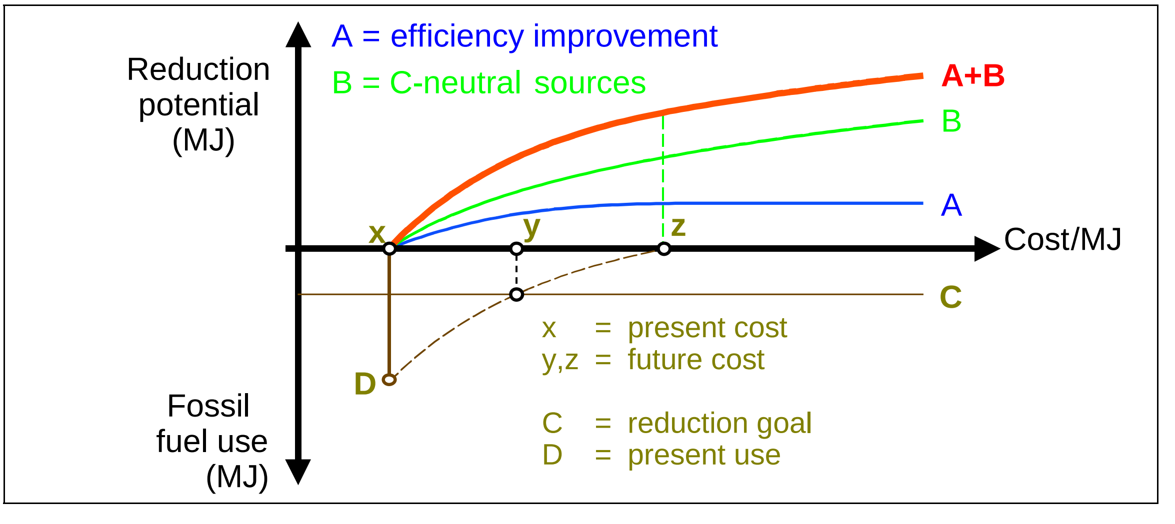

Fig. 8: Implementation of new energy technologies (energy efficiency, renewable energy sources) as a function of energy cost and corresponding reduction of fossil fuel use.

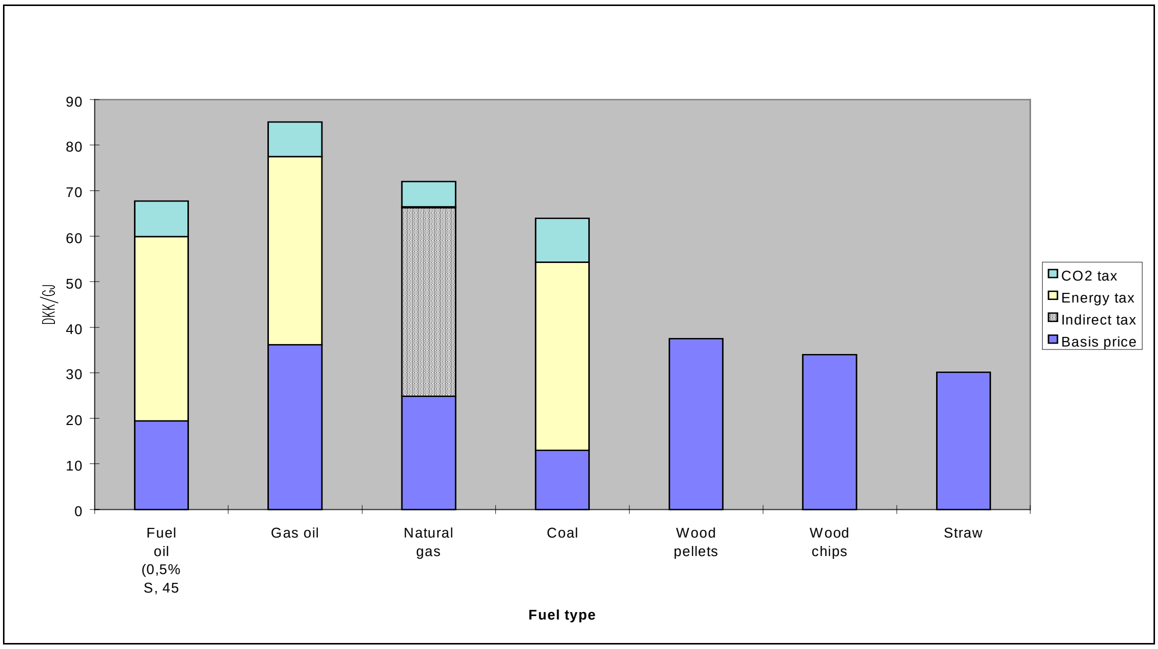

Fig. 9: Fuel prices in Denmark (dk Technik, Denmark)

An example for a taxation policy is shown in Figure 9 which illustrates the situation in Denmark: Fossil fuel prices are raised through taxation such that biofuels have become competitive.

Environment

Utilisation of bioenergy is associated with combustion processes whose emissions in many cases are potentially higher than those of natural gas or oil. In particular combustion of solid biofuels therefore require special equipment to meet the emission limits. This equipment has been developed in recent years such that standard emissions like CO, C_xH_y, NO_x and particulates generally are kept below the limits. Figure 10 show how this may be achieved through advanced combustion air control systems: the optimum rate of air supply is determined and set by a control system detecting the emissions in the flue gas.

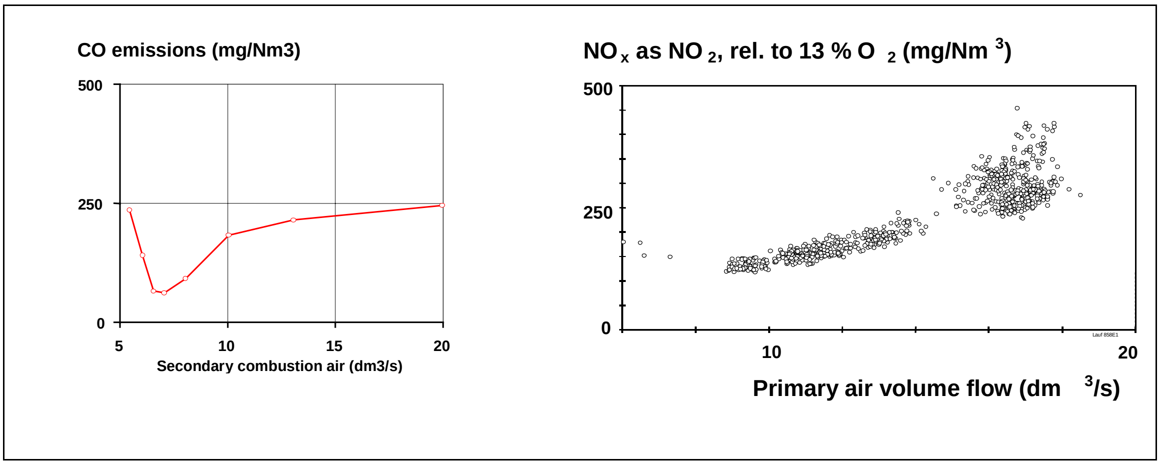

Fig. 10: CO reduction through secondary combustion air control (left); NOx reduction through primary combustion air control (right)

Regarding greenhouse gas emissions biomass can play a dual related to the objectives of the UNFCCC, i.e. as an energy source to substitute for fossil fuels and as a carbon store (Figure 11). Modern bioenergy options offer significant, cost-effective and perpetual opportunities toward meeting emission reduction targets while providing additional ancillary benefits. Moreover, via the sustainable use of the accumulated carbon, bioenergy has the potential for resolving some of the critical issues surrounding long-term maintenance of biotic carbon stocks. Finally, wood products can act as substitutes for more energy-intensive products, can constitute carbon sinks, and can be used as biofuels at the end of their lifetime (IEA Bioenergy 1998). The relationship between energy cost and the reduction of fossil fuel use through the reduction of fossil fuel use through the implementation of energy efficiency technologies and C-neutral energy sources is shown in the lower part of Figure 8. A major reduction of the current use of fossil energy sources, e.g. from level D to an acceptable level C, will be achieved if energy cost would rise from the level x to the level y. This will have a substantial impact on the world economy. To initiate the steps necessary for this transition is the main challenge for policymakers today.

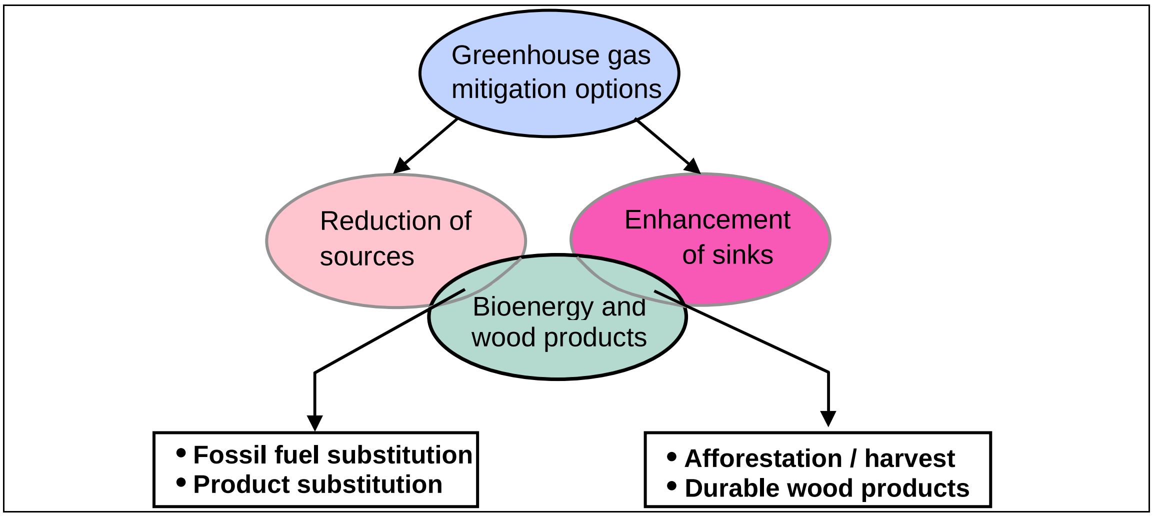

Fig. 11: Role of biomass in greenhouse gas mitigation.

References

IEA Bioenergy 1998: Annual Report 1998 of the Bioenergy Research network of the International Energy Agency (www.ieabioenergy.com)

IEA Bioenergy 1999: Annual Report 1999 of the Bioenergy Research network of the International Energy Agency (www.ieabioenergy.com)