ELSEVIER

Energy Policy. Vol. 25, No. 6, pp. 545–554, 1997

0301-4215/97 $17.00 + 0.00

PII:S0301-4215(97)00043-8

The economics of biomass in industrialized countries: an overview

Marian Radetzki
SNS Energy, PO Box 5629, 114 86, Stockholm, Sweden.

Biomass accounts for 3.5% of primary energy use in the OECD region, and 3.1% of final energy consumption. Biomass is the source of 14% of total heat produced in the region. Its role in electricity production (1.4% of total) is much less significant. Most biomass energy is consumed by households (wood burning) and paper pulp and wood industries. The political and public interest in expanded biomass use is based on the supposition that the external costs of this fuel are much smaller than those of coal, oil and gas. Comparison of full social costs are very hard to make, since uniform value measures of the respective external costs do not yet exist. The scattered and limited assessments that are available suggest that the difference between biomass and fossil fuels in this regard may have been exaggerated in policy debates, and may not be sufficient to warrant a large-scale expansion of biomass use. © 1997 Elsevier Science Ltd.

Keywords: Biomass; External costs; Competitiveness; Socially optimal use

Introduction

A recent assessment by the World Energy Council (WEC, 1993) suggests that in 1990 biomass usage in all forms, corresponded to 1070 MTOE, or 12% of global primary energy consumption, assessed at 8811 MTOE in that year. More than 80% of this total occurred in developing countries, and a dominant share was absorbed within the subsistence sector, without ever reaching commercial markets. Data on such consumption are inherently hard to obtain, and the figure provided by the World Energy Council is no more than a qualified guess. Even if the quoted figures were to provide a correct reflection of biomass input at the primary energy stage, they exaggerate its importance. This is because the efficiency of biomass usage in the subsistence sectors of developing countries is quite low (Shell, 1994), reducing the utility derived from this fuel.

This paper[1], and the conference at which it is to be presented, deals with biomass usage in the energy systems of industrialized countries, a small sub-set of the global total. Out of overall primary energy consumption in the OECD area in 1992, 4333 MTOE, biomass in all forms accounted for 161 MTOE, or 3.7% (IEA, 1995). At this level of usage, biomass was the dominant renewable energy source, far ahead of hydro (101 MTOE), and all other renewables, comprising geo, solar and wind (27 MTOE).

[1]Competent research assistance by Åsa Ahlin is gratefully acknowledged.

A significant proportion of the biomass that is consumed in industrialized economies is traded in markets, is often consumed in sizable plants, and hence is much easier to map statistically. The OECD volume and share of biomass usage are therefore on a much firmer ground than the corresponding global numbers.

The circumstances under which biomass is supplied and consumed, differ markedly between industrialized and developing countries, and warrant separate analytical treatments and approaches. The choice of industrial countries as the focus of the present study is prompted, in part, by the greater ease with which economic analysis can be applied in the presence of firmer data and market signals. The focus is also prompted by a wish to verify the solidity of frequent assertions that biomass provides a socially superior alternative to fossil fuels, and that it could potentially play a much expanded role in the energy systems of the rich market economies (Grassi et al., 1992; Johansson et al., 1993; McGowan, 1991). It would appear that the contemporary debate on the role of biomass in the OECD countries is dominated by engineers who conceive the equipment and plant for its use; and by true believers in the advantage of this resource, no matter at what cost. An important motivation for the present paper and the conference, therefore, is to insert some arguments about economic choices and rationales into this debate.

The primary purpose of the paper is to provide an overview and context for the following conference deliberations. To do this, the paper lists and briefly explores the issues and factors that have aroused the strong interest in biomass as an energy source, that explain its limited current role in the energy systems of rich countries, and that will determine its future potential. Several of the issues brought up on the following pages are treated much more profoundly and in considerably greater detail in the papers to be dealt with in the following conference sessions.

The discourse proceeds as follows. Section 2 distinguishes between the main sources of biomass supply in advanced economies, and provides some quantitative dimensions of biomass use in selected countries. In section 3, the reasons for the strong political and public interest in this energy resource are reviewed. Section 4 suggests an approach for determining the socially warranted level of biomass consumption in rich societies. Section 5 contains an attempt to practice, at least the first steps, of this approach. Scattered data on prices and costs of alternative fuels are presented, so as to provide a context for evaluating the commercial and social competitiveness of biomass in the energy systems of advanced economies. Section 6 summarizes the conclusions.

Sources of supply and quantitative dimensions

The sources of biomass supply can be categorized in different ways, and the dividing lines between categories are not always clear. The following analyses consider three main sources, *viz.*, (a) forest-based, (b) agriculture-based, and (c) that derived from waste of municipal or industrial origin. In the 1990s, the forest-based and agriculture-based sources of biomass supply for energy use have been dominated by residues, but purpose-grown biomass crops are assuming increasing significance. Short-rotation wood crops, usually grown on surplus agricultural land (eg, poplar and willow), are included in the agriculture-based category.

The IEA regularly compiles data on biomass supply and use (IEA annual). The categorizations employed by this source, lose an important policy dimension because they do not distinguish between the forest-based and agriculture-based sources of supply. As appears from the excerpted statistics for the OECD as a whole and for selected OECD countries, presented in Table 1, a distinction is made between solid biomass derived from both forestry and agriculture, on the one hand, and waste, of municipal and industrial origin, respectively, on the other. All the numbers are expressed in TWh, using the following conversion rates: 1 TWh =3.6 PJ =0.086 MTOE.

The statistics presented in IEA's annual compilations are incomplete in some respects, and inconsistent in others. For instance, it appears that several countries, eg, Canada, France (and the UK in some measure), do not provide data on the supply and energy usage of waste materials. Also, the figures, for example Sweden, imply that the biomass not employed in final energy consumption, is converted into electricity and heat at 100% efficiency, which cannot be true.

Despite these deficiencies, the compilations permit several interesting observations: (a) Biomass accounts for some 3.5% of total primary energy supply (TPES) in the OECD area (an assessment reasonably close to the 3.7% estimate for 1992 from another IEA source quoted above), and 3.1% of total final energy consumption (TFC); (b) Biomass is the source of 14% of total heat produced in the region, but only 1.4% of total power production. The small proportion of electricity needs satisfied by biomass is explained by the very substantial efficiency losses in converting this energy material into power; (c) Solid biomass of forest and agricultural origin dominates the total, and accounts for 86% of overall primary biomass supply. The high figure may be due to the incomplete coverage of waste supply; (d) Virtually all final biomass consumption occurs in the paper, pulp and wood industry sectors, using residues for internal energy generation (44%), and the residential sector (48%), the latter predominantly involving wood burning. Biomass usage in transport is insignificant; (e) Canada, Sweden and the US, three countries with large forests and sizable wood and paper industries, account for 70% of total non-waste biomass supply generation in the OECD area, and their paper, pulp and wood industries absorb more than 90% of the region's final consumption of this energy material. This suggests that forest related industries are driving forces both in the supply and the use of biomass, and that forest-based biomass is far more important than that from agriculture. If the three nations are excluded, the share of biomass in remaining OECD countries' TPES shrinks from 3.5% to only 2.3%.

Why the interest in biomass energy?

Historically, biomass, supplemented by other renewables like hydro, wind and solar, has dominated global energy use. Coal consumption in Britain took on significance only in the beginning of the 18th century, in consequence of the increasing scarcity of wood fuel (Maurice and Smithson, 1984). Global assessments suggest that as recently as 1860 wood consumption for energy purposes was twice as large as consumption of coal, the second largest energy source at that time, and that coal overtook wood as the dominant fuel only in 1880 (Ausbel et al., 1988). In the first half of the present century, however, fossil fuels have assumed an increasing dominance in satisfying the world's energy needs, with the shares of wood and other renewable energy sources shrinking into insignificance. Oil overtook coal as the leading energy material about 1970, gas has emerged as an increasingly important fuel, and nuclear experienced an explosive, though short-lived growth from the mid-1960s to the mid-1980s.

The conquest of energy markets by fossil fuels had to do with the high concentration and transportability of the energy that such fuels contain but that biomass lacks. Work on renewable energy conversion technologies was gradually abandoned, as these energy forms lost their former importance.

The interest in biomass and other renewables in the industrial market economies was revived about 1970. This interest has since then gone through several distinct phases characterized by alternative concerns prompting the promotion of renewable energy sources. 'Promotion' is a key word in this context. Some use of biomass has always occurred

Table 1 Energy supply and consumption in selected OECD countries in 1993

OECD
TWh

	TPES	TFC	FC bio		Electricity produced	Heat produced
			Paper, pulp, and wood industries	Residential		
Total energy	51,052	36,212			7657	346
Bio+waste	1762	1118	495	534	105	47
of which Solid bio	1522	1084	491	511	65	31
Biogas+liquids	43	1	0	0	5	0
Municipal waste	115	4	4	0	15	14
Industrial waste	83	28	1	23	20	1

OECD Europe
TWh

	TPES	TFC	FC bio		Electricity produced	Heat produced
			Paper, pulp, and wood industries	Residential		
Total energy	16,757	12,174			2488	226
Bio+waste	426	337	83	219	22	36
of which Solid bio	345	306	78	196	10	23
Biogas+liquids	5	1	0	0	1	0
Municipal waste	44	4	4	0	7	12
Industrial waste	32	26	1	23	4	0

Canada
TWh

	TPES	TFC	FC bio		Electricity produced	Heat produced
			Paper, pulp, and wood industries	Residential		
Total energy	2567	1966			527	3
Bio+waste	102	99	76	23	4	—
of which Solid bio	102	99	76	23	4	—
Biogas+liquids	—	—	—	—	—	—
Municipal waste	—	—	—	—	—	—
Industrial waste	—	—	—	—	—	—

Denmark
TWh

	TPES	TFC	FC bio		Electricity produced	Heat produced
			Paper, pulp, and wood industries	Residential		
Total energy	230	175			34	31
Bio+waste	15	6	1	4	0	6
of which Solid bio	9	6	1	4	0	3
Biogas+liquids	0	0	—	0	0	0
Municipal waste	5	—	—	—	0	4
Industrial waste	—	—	—	—	—	—

France
TWh

	TPES	TFC	FC bio		Electricity produced	Heat produced
			Paper, pulp, and wood industries	Residential		
Total energy	2719	1770			472	—
Bio+waste	49	47	—	40	1	—
of which Solid bio	49	47	—	40	—	—
Biogas+liquids	—	—	—	—	—	—
Municipal waste	—	—	—	—	—	—
Industrial waste	—	—	—	—	1	—

Germany
TWh

	TPES	TFC	FC bio		Electricity produced	Heat produced
			Paper, pulp, and wood industries	Residential		
Total energy	3922	2828			526	97
Bio+waste	29	13	1	11	5	10
of which Solid bio	15	13	1	11	—	10
Biogas+liquids	—	—	—	—	0	0
Municipal waste	11	—	—	—	2	—
Industrial waste	3	—	—	—	3	—

Table 1 Continued

Netherlands
TWh

	TPES	TFC	FC bio: Paper, pulp, and wood industries	FC bio: Residential	Electricity produced	Heat produced
Total energy	810	641			770	6
Bio+waste	4	1	0	—	1	0
of which Solid bio	—	—	—	—	—	—
Biogas+liquids	1	1	0	—	0	0
Municipal waste	3	—	—	—	1	—
Industrial waste	—	—	—	—	—	—

Norway
TWh

	TPES	TFC	FC bio: Paper, pulp, and wood industries	FC bio: Residential	Electricity produced	Heat produced
Total energy	259	213			120	2
Bio+waste	12	11	6	5	0	1
of which Solid bio	10	10	6	5	0	0
Biogas+liquids	0	0	—	—	—	—
Municipal waste	1	—	—	—	0	1
Industrial waste	0	—	—	—	—	0

Sweden
TWh

	TPES	TFC	FC bio: Paper, pulp, and wood industries	FC bio: Residential	Electricity produced	Heat produced
Total energy	548	398			146	44
Bio+waste	72	57	45	11	2	13
of which Solid bio	68	57	45	11	2	9
Biogas+liquids	0	0	—	—	0	0
Municipal waste	4	—	—	—	0	4
Industrial waste	0	0	0	—	—	—

UK
TWh

	TPES	TFC	FC bio: Paper, pulp, and wood industries	FC bio: Residential	Electricity produced	Heat produced
Total energy	2524	1767			323	2
Bio+waste	11	—	—	—	1	0
of which Solid bio	4	—	—	—	0	—
Biogas+liquids	3	—	—	—	1	0
Municipal waste	3	—	—	—	0	0
Industrial waste	0	—	—	—	0	0

US
TWh

	TPES	TFC	FC bio: Paper, pulp, and wood industries	FC bio: Residential	Electricity produced	Heat produced
Total energy	23,593	16,360			3411	112
Bio+waste	1040	514	328	185	68	11
of which Solid bio	888	514	328	185	42	8
Biogas and liquids	38	—	—	—	3	0
Municipal waste	67	—	—	—	13	2
Industrial waste	48	—	—	—	10	1

Source: IEA (annual).

because it has been more economical than the use of fossil fuels. Promotion involves tax relief or subsidization of some sort with the aim to raise biomass use to a higher level than would have occurred in the absence of such measures. The successive motivations for such promotion will be presently reviewed.

Very high economic growth was recorded by the industrialized market economies through the 1960s, and energy usage, dominated by fossil fuels, increased at even higher rates. The initial call for measures to promote the development of alternative energy sources, including renewables like biomass, was prompted by a belief that oil and other cheap fossil fuel resources would be rapidly depleted. The Club of Rome publications from before the first oil crisis, reflect the mood of impending exhaustible resource scarcity and expectations of rising prices, that prevailed at the time (Meadows et al., 1972). Early efforts to develop replacements were seen as a means to avoid the anticipated problems.

Fossil fuel prices did indeed rise in consequence of the oil crisis of 1973/74, which was interpreted by many observers at the time, as importantly caused by depletion. But the market interventions of OPEC and the political actions by individual members of the cartel in the late 1970s and early 1980s brought the security of supply issue to the forefront of energy policy debates in industrialized countries (Finon, 1994). Promotion of biomass, a renewable and basically domestic resource, was now seen to provide double protection, both against rising prices due to depletion, and the political insecurity of foreign energy supply.

The concerns about rising prices due to resource depletion and energy supply security, subsided substantially after the sharp oil price decline of the mid-1980s. Ceteris paribus, the lower price of fossil fuels constrained the competitiveness of biomass and other renewables. The pleas for promotion of such fuels nevertheless remained, and were even accentuated. However, the motives for such promotion during the most recent decade have been distinctly different from the ones that prevailed before.

Special support for biomass use as an energy source has recently been incited by two arguments, one having to do with surplus agricultural land, the other with the environment.

Rising agricultural productivity in the rich industrial economies has led to growing food surpluses and agricultural policies restraining land use for food production. In this situation, the agricultural lobby has pleaded for support to energy crops, arguing that biomass production for energy purposes yielded a substantial social benefit in the form of added agricultural employment, and that, in any case, the use of fallow land carried zero alternative cost.

From the beginning of the 1990s, climate change has become a vociferous issue in the industrialized countries' environmental policy debates. Carbon taxes have been introduced in some countries and are being discussed in many others, as a means to reduce fossil fuel use, and the negative external effects caused by carbon emissions from the burning of such fuels. Biomass, in contrast, is seen as a preferred fuel in this respect, because it is a renewable resource, and any carbon emissions from its use are reabsorbed by the vegetal growth from which it is derived. This characteristic of biomass, therefore, is employed as a motive for its promotion.

Thus, employment of agricultural labour and fallow land, and environmental superiority appear to be the overriding motives currently in vogue for promotion of biomass use in the energy systems of rich industrial countries. These motives, but not the earlier ones, will be further considered in the following section where an attempt is made to design an approach for determining the socially warranted level of biomass consumption.

Guiding principles for determining the optimal level of biomass consumption

The principles to accomplish this task are quite simple. The practice, in contrast, is messy and unclear. Some practical hunches to resolve the latter are provided in the following section, with further details contained in the other papers presented to this conference.

Fossil fuels dominate energy consumption, in the world as well as in the OECD area. Fossil fuels are widely internationally traded. With few exceptions, individual countries can be regarded as price takers in the international market. Imports by a single country can be increased within a very wide range without a perceptible impact on the international price. Furthermore, there is a broad tendency for the prices of individual fossil fuels to develop in parallel, with a large inconvenience discount for coal and a lesser one for gas, from the price of oil, all expressed per unit of energy

From an individual consuming country's point of view, therefore, the price of fossil fuels at a particular point in time, can be seen as a horizontal line, irrespective of the volume consumed, as represented in Figure 1.

The supply curve for biomass can assume different forms, depending on the source, and the preconditions under which its availability can be increased. However, given the typically low energy density of biomass, and its low unit value, the transportability of this material is limited, with rising costs at the point of delivery, as the area of supply is widened. An upward-sloping biomass supply curve, as represented in Figure 1, therefore, should be common.

The commercially optimal volume of biomass consumption in terms of Figure 1, would equal B, the level at which the marginal cost of biomass supply equals that of fossil fuels. Beyond this point, biomass becomes more expensive than fossil fuels, so the remaining energy consumption needs (T–B) should be satisfied by the latter.

External effects have to be considered in order to determine the socially optimal volume of biomass consumption. If biomass use yields external benefits which cannot be reaped by its suppliers (eg, socially valuable employment generation), then this benefit should be deducted from the commercial cost of supply. The supply curve would move to the right in consequence, and raise the optimal level of biomass use. If fossil fuels yield external

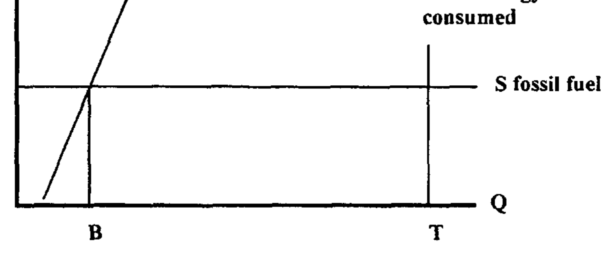

Figure 1 The optimal level of biomass use

costs (eg, environmental damage), then these costs should be added to the commercial cost of supply. The supply curve for fossil fuels would move up in consequence, and, likewise, increase the optimal level of biomass use. Such external benefits and costs can be internalized through the use of subsidies (for biomass) and taxes (for fossil fuels). The intersection between the two supply curves, appropriately adjusted for the external effects of the respective fuels, will determine the socially optimal volume of biomass consumption.

Some hunches about the determination of optimal levels of biomass consumption in practice

This introductory and overview paper is not the place to finalize the very complex commercial and socio-economic assessments and their quantitative implications for biomass competitiveness and use. Instead, the purpose of this section is to provide some starting points and leads for more detailed investigations of the competitiveness of such fuels. The analysis of this section proceeds in the same order as that of the preceding one, starting out with the market prices of fossil fuels and the costs and cost functions of biomass, and then continuing with some hints about the types of external effects that have to be taken into account, and their relative importance.

Fossil fuel prices

Table 2 displays current fossil fuel prices and an authoritative forecast of their development over the coming decade. To provide a better comparison between the fossil fuels, and with the costs and prices of biomass, provided below, the figures are also expressed in US cents KWh^{-1} gross energy content. With appropriate adjustments for transport costs and other considerations, the numbers could be used as a starting point in constructing the flat national supply curves for fossil fuels, depicted in Figure 1. These, then, are the indicative prices (excluding taxes) with which biomass has to compete.

Some indicators of biomass costs and prices[2]

Comparisons of the prices for fossil fuels with biomass prices are very hard to make, because, so far, at least, there are very few published price quotations for biomass products. Some insights into the competitiveness of biomass as an *input into energy production* are available in a Swedish investigation (NUTEK, 1993), which provides scattered data on costs and prices in the early 1990s, based on responses to questionnaires by public bodies in different countries. These are all expressed in US cents KWh^{-1} gross energy content.

The forest residue prices quoted in this paragraph comprise the cost of 50 km transport. Wood chips from sawmills were priced at US cents 0.61 KWh^{-1} in the US, and a range of US cents 1.25 (Portugal) – 3.27 (Netherlands) for selected European countries. Sawdust, bark and other sawmill residues could be had at US cents 0.39 in the US and a range of US cents 0.52 (Sweden) – 1.68 (Netherlands) in Europe. Inferior pulpwood was charged at US cents 0.58 in the US and a range of US cents 0.71 (Sweden) – 3.47 (Switzerland) in Europe.

The same study quotes European prices of straw (agricultural residue) for energy use in a range between US cents 1.13 (Spain) – 2.22 (Denmark).

The cost of purpose-grown short rotation forest, including short-haul transport, has been assessed at US cents 1.02 KWh^{-1} in Sweden, 0.97 in the European Union (NUTEK, 1993), and in a range between US cents 0.97 and 1.38 in the USA (Larson and Williams, 1993).

To the extent that they are representative, the above prices and costs suggest that some, but not much, biomass supply, could compete with coal for heat and power generation. Internal use of forest residues by the wood and paper industries, and household wood burning are prime examples.

The competitiveness would be further weakened when measured at the 'final energy output stage', by the higher capital and operating cost per unit of heat and power capacity in plants built for biomass, compared to plants using coal.

[2]The data contained in this sub-section have been compiled by Lars Johan Lindborg, Division of Economics, Luleå University.

Table 2 Price forecasts for fossil fuels, constant 1995 $

	1990	1995	2000	2005	US cents KWh^{-1}			
					1990	1995	2000	2005
Oil, $ $barrel^{-1}$	26.3	17.0	15.8	15.7	1.75	1.13	1.05	1.04
Coal, $ ton^{-1}	48.1	40.0	39.5	39.3	0.63	0.52	0.51	0.51
Gas, $ $mmBTU^{-1}$								
USA	1.96	1.65	1.94	2.12	0.67	0.56	0.66	0.72
Europe	2.93	2.70	2.37	2.28	1.00	0.92	0.81	0.78

Commodity description and place of market:
Oil: Spot average of Brent, West Texas and Dubai.
Coal: Thermal, 26,400 BTU kg^{-1}, FOB, US East Coast.
Gas US: Spot at Henry Hub, Louisiana.
Gas Europe: Average import border price.
Source: World Bank (1995).

The cost difference of power plants using alternative fuels emerges starkly in a comparison between electricity generation using municipal solid waste, on the one hand, and coal, on the other Table 3. The following compilation is based on IEA (1993). The figures reflect costs per KWh of *final electricity output*. They comprise the efficiency losses in electricity generation, and are therefore not comparable to the ones quoted in earlier paragraphs. Plant capacity costs for municipal waste usage are twice as high as those for coal; operating costs are six times higher. The negative cost of municipal waste has been set so as to make the total cost of electricity equal in the two cases. Those who dispose of municipal waste must be prepared to pay the power station no less than US cents 6.4 KWh^{-1} final electricity, for this mode of generation to be competitive with coal. As shown in another paper to this conference (Miranda and Hale, 1997), such preparedness to pay could frequently occur in densely populated areas, where the disposal of municipal and industrial waste carries a high cost.

At a more general level, Shell (1994) assesses the fossil-fuelled power generation costs globally, to fall in a range of US cents 3.5–6.5 KWh^{-1}. The range for biomass power generation is given at US cents 5–15 KWh^{-1}, suggesting, again, some, but not much, commercial competitiveness for this fuel.

A recent IEA study (IEA, 1994) concludes that the total cost of producing ethanol from purpose-grown maize, wheat and sugar beet, or rape seed oil from rape seed, in the US and EU in the early 1990s, is 3–8 times the price of the gasoline and diesel fuel that they replace. The study aso considers the cost of electricity from purpose-grown short rotation forestry, and concludes that such electricity costs work out at 1.5–2 times the costs of new facilities using fossil fuels.

At the final energy output level, too, the figures convey a strong impression that biomass is seldom commercially competitive with fossil fuels.

The shape of biomass supply curves

The representative single point cost and price figures presented above do not provide any feeling about the shape of the biomass supply curve. If this curve is upward-sloping, the low cost portion of supply may indeed be very competitive with alternative fuels. But an upward slope also imposes an economic restriction on the expansion of biomass, since increasing quantities will then only be obtainable at rising costs and prices. The following paragraphs argue that the biomass supply curve does indeed have an upward slope, as depicted in Figure 1, rendering this resource increasingly uncompetitive with the flat-priced fossil fuels, as the volumes of biomass are increased.

As noted in the preceding section, biomass typically represents low values per unit of volume and weight. It follows that transport weighs heavily in the total cost of supply at any point of delivery beyond the immediate vicinity of production. It may therefore be instructive to distinguish between the cost of supply at the production point, on the one hand, and at the large customer's gate, on the other. Consider first the shape of the supply curve at the production point.

The availability of biomass in the form of 'residues' at the production point, is given by the level of the primary activity in which the residues are generated. Thinning and harvesting of forests, the volume of agricultural output, the level of industrial activity and the size and wealth of cities are the main determinants of biomass availability in the form of residues from the four sources. Given the levels of primary activity, the cost of biomass supply will increase monotonically with the intensity of collection. The higher the price paid for the residues, the more intensively will it be worthwhile to collect them. In the extreme (and unlikely) case where the residue price exceeds the primary product price, the biomass supply curve could become extremely elastic, because it would then be economical to supply the primary produce (wood, wheat) for biomass use. In the case of industrial and municipal waste, a cost is often involved with residue deposition (Miranda and Hale, 1997), so that it may be economical to dispose of such residues by paying the biomass user. Ceteris paribus, the lower the charges imposed by the biomass collector, the more waste will be provided for biomass use. In all the cases considered here, the supply curve for biomass based on residues at the point of production, is upward-sloping.

Within very wide ranges, the same is not true for 'purpose-grown' biomass. So long as fallow land is available, and given reasonable lead time, it should be possible to expand the supply of willow or other crops suited for energy production at constant cost of output.

However, as shown in two other papers to this conference (Lunnan, 1997; Sedjo, 1997), there is another serious problem confronting purpose-grown biomass for energy use. Since such biomass (wood, wheat) typically represents much higher values in the pulp and food industries, most available supply is bid away by such industries at prices that the energy producers cannot afford, with small volumes, if any at all, reaching the energy sector.

In any case, it is clear that at the large customer's gate, all biomass curves will be upward-sloping. Greater supply at a given point of delivery will require a larger area of residue collection or energy cropping. This, in turn, will result in higher average and marginal cost of transport. The steepness of the supply curve for residues will increase in

Table 3 **Levelized electricity generation costs, US cents KWh^{-1} of electricity output**

	Investment	Operating	Fuel	Total
Coal	1.7	1.2	1.9	4.8
Municipal waste	3.8	7.4	–6.4	4.8

Source: IEA (1993).

consequence, and an upward slope will apply also to the supply curve for purpose-grown biomass.

The upward slope of biomass supply at the point of use will tend to favour small consumption units relying on local supply. This would be particularly pertinent in the case of biomass from residues, whose supply curves have steep slopes. Biomass would face a special disadvantage in relation to fossil fuels where the plant converting the energy raw material to final energy is subject to strong economies of scale.

Actual biomass use is shaped not only by the prices and costs, of which some indications have been provided above, but importantly, also, by a plethora of subsidies and taxes, usually favouring biomass, and changing erratically over time.

Technological progress and competitiveness

Analyses of the competitiveness of biomass often conclude that technical progress in the production and supply of this resource, and in its use for energy generation, will gradually make it more competitive with fossil fuels. This assertion appears to neglect the fact that the cost of fossil fuel supply has been declining, in consequence of impressive productivity improvements (Ellerman, 1995; Shell, 1989), forcing price declines of greater magnitude than those envisaged in the forecasts of Table 2. It also neglects the similarly impressive cost-reducing technological advances in the transformation of fossil fuels to final energy. The increasing fuel efficiency of automobiles is one example, that of gas fuelled power generation is another (Radetzki, 1994). For increasing competitiveness, the productivity improvements in biomass production and utilization must proceed at a faster pace than those relating to fossil fuels. This remains to be demonstrated.

External effects

Those who favour a wider biomass use often point to the negative external effects of fossil fuel consumption, and contend that fossil fuels will become uncompetitive if these effects are fully internalized. The external effects under discussion are predominantly related to environmental damage, though issues of health and safety are often also considered. CO_2-emissions from fossil fuel burning have played a key role in the debates of the 1990s around these themes. The external benefits of using fallow land, or of added agricultural employment from expanded biomass use, in contrast, have received less attention in recent social evaluations of this fuel, perhaps because if the land and labour used are truly redundant, then their low or zero cost should be easy to internalize in the commercial cost of output.

A proper socio-economic evaluation of the merits of alternative fuels should obviously consider the external effects of each. The practice of doing so is in its infancy, and raises formidable problems. A first difficulty arises in identifying the external effects that should be taken into account. A second, probably more serious, is in assigning monetary values to such effects, to permit economic comparisons between the fuels under consideration. Subjective value judgments cannot be avoided, when comparing, for instance, the detriment of potential climate change, on the one hand, with that of acid rain, on the other. Further difficulties arise from the absence of firm methodological support in resolving issues of uncertainty and risk, or of choice of discount rate.

Given the role of value judgments and methodological voids surrounding the analysis of external costs, almost any statements can be made in support of one view or the other, all with seemingly impressive scientific support. The purpose of the following paragraphs is not to resolve this complex issue, but to point to some ongoing work, and to indicate the very tentative conclusions that appear to be emerging.

A recent study (ÅF Energikonsult, 1995) yields the following environmentally harmful airborne emissions from modern combined heat and power plants using wooden biomass and natural gas, respectively, as fuel. The figures in Table 4 relate to the full life cycles for the respective fuels.

The table shows biomass to be clearly superior in terms of CO_2 and CH_4, the two greenhouse gases emitted in the process of burning the respective fuels. In terms of all other emissions, biomass is inferior. In addition, biomass leads to significant airborne emissions of heavy metals like nickel, cadmium and lead, and generates 7000 micrograms of ash MWh^{-1} which should preferably be returned to the forest plantation at an additional cost, to avoid large-scale chemical fertilizer use. Gas is not afflicted by these environmental detriments. The study makes no attempt to put values on the enviromental impacts, nor even to assess their relative weights.

IEA (1994) quoted before, also employs life cycle analyses to assess the savings in CO_2-emissions from using agriculture-based ethanol and rape seed oil as substitutes for gasoline and diesel fuel. Assuming currently applied standard technology using fossil energy and grid electricity in the production

Table 4 Emissions from burning wooden biomass and natural gas in combined heat and power plants in Sweden. Milligrams per KWh of final energy

	Biomass	Gas		Biomass	Gas
Particulates	72	0	NH_3	8	0
NO_2	403	216	N_2O	47	22
S	47	2	CH_4	1	159
CO_2	1052	255,400	VOC[a]	19	8
CO	428	144			

[a]Volatile Organic Carbon.
Source: ÅF Energikonsult (1995).

of these biofuels, the study concludes that the CO_2-emissions from producing ethanol work out at 80–95% of what they would have been if gasoline were used in the first place, in the case of ethanol. In the case of rape seed oil, however, the CO_2-saving amounts to 50% of those that would occur if diesel had been used. It appears that the biofuels analysed by the IEA are not entirely innocent in terms of greenhouse warming. A social evaluation must juxtapose their much higher costs with the limited CO_2-reductions made possible by their use.

In 1991, the US and the European Community signed a joint protocol to carry out a set of studies in this particular field. The work aimed at clarifying and putting values on externalities in 'power production' using coal, oil, gas, uranium and biomass as fuels. A major goal was to identify critical methodological and information needs. The final results of the work carried out so far were published in 1995 (EXTERNE, 1995).

The assessments contained in this work and summarized in Table 5, are admittedly incomplete. The authors have been unable to put values on some of the external cost items. Biomass was not assessed in this round. The (high) outlier numbers for climate effects, quoted in the study, have not been comprised in the numbers presented below. The methods to derive the figures are opaque. The results are subject to different interpretations. The numbers refer to West European conditions. The external costs presented in the table are related to the total internal cost of power generation as given in the accounts of power producers, assessed at 5–6 US cents KWh^{-1}.

It is noteworthy that another, equally serious, piece of research on the same matter, 'The New York Environmental Externalities Cost Study' (Rowe, 1995), completed at about the same time as the EXTERNE-study, came to dramatically different results. Because of the huge range of uncertainties, it excluded the climate effects from consideration. The total of remaining external cost categories at a specific site in New York State, expressed in US cents KWh^{-1} power output, work out at 0.23 and 0.09, respectively, for traditional and advanced coal power stations, 0.14 for oil, 0.02 for gas, 0.01 for nuclear, and the highest, 0.31, for wooden biomass. The comparison between the two studies is revealing. Compared to the non-climate categories in the EXTERNE-study, these numbers work out at about one tenth for coal and oil, and one fifth for natural gas and nuclear power. This points to the extreme uncertainties surrounding the issue under investigation.

Taking the external effects into account might well shift the supply curves of fossil fuels and biomass in Figure 1 in favour of the latter. But with the present state of knowledge, it is unclear how large the shifts will be. The available numbers suggest that even after such an adjustment, biomass would remain a somewhat marginal raw material in the energy sectors of industrialized countries. This conclusion is reinforced by the earlier observation that most of the supply of purpose-grown biomass is likely to be bid away for higher-value uses in the pulp and food industries.

Conclusion

Biomass of different origins accounts for some 3.5% of total primary energy use in the OECD countries. Forest residues are the most important source, and a large part of final biomass consumption occurs in the forest and forest-related industry sectors.

The reasons for policy makers' interest in biomass energy have varied over time. In the 1990s, concerns with greenhouse warming have made biomass appear especially attractive, for in distinction to fossil fuels, burning of biomass is widely believed not to yield any net addition to greenhouse gas emissions over time. For this and other reasons, biomass is favourably treated in the energy policies of many countries.

Very scattered evidence is available on the costs and prices of biomass supply. Available data suggest that only limited amounts of biomass are commercially competitive with fossil fuels. The dominant proportion of biomass currently in use is derived from residues. This source has a limited supply, determined by the primary activity in which the residues are generated. Because of high transport costs, all biomass supply curves are upward-sloping. Increasing usage will therefore involve declining competitiveness.

All energy uses give rise to external effects, mainly in the form of environmental damage. A proper socio-economic evaluation of alternative fuels must take such effects into account. There is even less quantifiable evidence on such external effects and their monetary equivalents. Findings from ongoing studies suggest that the external costs of biomass are higher than the ones arising from the use of fossil fuels, with one very important exception. Fossil fuels add more to greenhouse warming, than biomass. The competitiveness of biomass vs fossil fuels will improve or deteriorate when extenal effects are taken into account, depending on the relative importance attached to greenhouse warming and other environmental damage, respectively.

Table 5 External costs of power generation in Western Europe. US cents KWh^{-1}

	Coal		Oil		Gas					
	Max	Min	Max	Min	Max	Min		Nucl	Wind	Hydro
Climate	2.2	1.2	1.5	0.7	1.0	0.5	Acid	0.01		
Other	1.9	0.7	1.4	1.3	0.1	0.1	Other	0.03		
Total	4.1	1.9	2.9	2.0	1.1	0.6	Total	0.04	0.3	0.3
% of internal cost	75	35	50	35	20	10		1	5	5

Source: EXTERNE (1995).

References

ÅF Energikonsult (1995) 'Energi och miljö' (Energy and environment), by A K Hjalmarsson *et al* 4 December, Stockholm

Ausbel, J H, Gruebler, A. and Nakicenovic, N (1988) 'Carbon dioxide emissions in a methane economy' *Climatic Change* No 12

Ellerman, D (1995) 'The world price of coal' *Energy Policy* Vol 23, No 6

EXTERNE (1995) *Externalities of Energy* Vol 1: Summary, European Commission, EUR 16521, Brussels

Finon, D (1994) 'From energy security to environmental protection: understanding swings in the energy policy pendulum' *Energy Studies Review*, Vol 6, No 1

Frankenhauser, S (1993) 'The economic costs of global warming: some monetary estimates' in Kaya Y *et al* (eds) *Costs, Impacts and Benefits of CO_2 Mitigation* IIASA, Austria

Grassi, G, Collina, A, and Zibetta, H (eds) (1992) *Biomass for Energy, Industry and Environment* 6th EC Conference, Elsevier Applied Science Press, London

IEA (1993) *Projected Costs of Generating Electricity* OECD, Paris

IEA (1994) *Biofuels* OECD, Paris

IEA (1995) *World Energy Outlook* OECD, Paris

IEA (annual) *Energy Statistics of OECD Countries* OECD, Paris

Johansson, T, Kelly, H, Reddy, A and Williams, R (eds) (1993) *Renewable Energy: Sources for Fuels and Electricity* Island Press, Washington DC

Larson, E and Williams, R (1993) 'Advanced gasification-based biomass power generation' in Johansson T B, Kelly H, Reddy A K N and Williams R H (eds) *Renewable Energy: Sources for Fuels and Electricity* Island Press, Washington DC

Lunnan, A (1997) 'The economics of agriculture-based biomass energy supply' (in this volume)

Maurice, C and Smithson, C (1984) *The Doomsday Myth* Hoover Institution Press, Stanford, California

McGowan, S (1991) 'Controlling the greenhouse effect: the role of renewables' *Energy Policy* March

Meadows, D *et al* (1972) *The Limits to Growth* Universe Books, New York

Miranda, M and Hale, B (1997) 'Waste not, want not: the private and social costs of waste-to-energy production' (in this volume)

NUTEK (1993) *Forecast for Biofuel Trade in Europe* B 1993:10, Stockholm

Radetzki, M (1994) 'World demand for natural gas: history and prospects' *Energy Journal* Vol 15, special issue

Rowe, R (1995) 'The New York environmental externalities cost study: summary of approach and results' paper for Workshop on the External Costs of Energy, organized by the EC and IEA-OECD, Brussels, Jan 30–31, 1995

Sedjo, R (1997) 'The economics of forest-based biomass supply' (in this volume)

Shell (1989) *Producing Oil and Gas* Shell Briefing Service, No 4

Shell (1994) *Renewable Energy* Shell Briefing Service, No 1

WEC (1993) *Energy for Tomorrow's World* St Martin's Press, New York

World Bank (1995) *Commodity Markets and the Developing Countries.* November