5 Biomass

5.1 Biomass energy – An overview

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5.1.1 General overview

Availability, reliability, affordability and security of energy are key factors in social and economic development. This has been true for the past and will remain so in the future. But the type of energy and the way we produce and use it changes over time, reflecting energy, economic, social, political, and evolving technical changes. Predicting such changes is notoriously difficult since such predictions have so often proved to be completely wrong.

Biomass energy is experiencing a surge in interest in many parts of the world due to a combination of factors including

- the profound transformations of the energy market worldwide, driven by privatization, deregulation, decentralization and concern with the environment;
- greater recognition of its current role and future potential contribution as a modern energy carrier;
- increasing concern about rising oil prices and vulnerability of supply;
- availability, versatility, and sustainability of bio energy;
- better understanding of its global and local environmental benefits;
- perceived potential role in climate stabilization;
- existing and potential development and entrepreneurial opportunities;
- technological advances and knowledge which have evolved recently on many aspects of biomass energy;
- growing interest in renewable energy in general, driven mostly by energy security and concern with potential implications of global warning.

An international study has revealed an almost universal optimism on renewable energy (RE) [01Mah]. The UNEP report also indicates that the market for clean energy technologies could be worth as much as $1.9 trillion by 2020 [02UNE]. Thus, has RE finally come to age? It remains difficult to say, but a number of specific factors indicate that it is moving in this direction at a growing pace. There are many encouraging examples:

1) Growing concern with global climate change may eventually drive a global policy on pollution abatement. For example, in The Hague's meeting COP6, despite its failure, it firmly established support for RE which could provide the basis for a global market.
2) At the Johannesburg World Summit in 2002, although there were modest achievements with regard to energy, the European Union (EU) presented a proposal to increase the share of RE in order to *"Diversify energy supply by developing cleaner, more efficient and innovative fossil fuel technologies, and by increasing the global share of renewable energy sources to at least 15% of global total primary energy supply by 2010. To achieve this, all countries should adopt and implement ambitious national goals for renewable energy. For industrialized countries, these goals*

should aim at an increase of the share of renewable energy sources in the total primary energy supply by at least 2 percentage points by 2010 relative to 2000" [02WSS].
This declaration has been followed up by various initiatives e.g. the EU's $700 million partnership initiative, or the agreement signed by 9 major electricity utilities with the UN to facilitate technology cooperation for sustainable energy projects in developing nations, etc.

3) The Latin American and Caribbean region also agreed in May 2002 on a proposal for targets and timeframes on RE to *"Increase in the region the use of renewable energy to 10% as a share of total energy by 2010"* [02ISC].
4) Growing recognition among established conventional energy institutions of the importance of biomass energy, e.g. a World Bank study concluded that *"Energy policies will need to be as concerned about the supply and use of biofuels as they are about modern fuels [… and…] they must support ways to use biofuels more efficiently and sustainably"* [96WOB].
5) Expected increase of energy demand, e.g. the IEA Energy Outlook [02IEA] estimates that non-hydro RE will grow by 3.3% annually from 2000 to 2030. The Global Environmental Facility (GEF) also predicts that developing countries alone will need as much as five million MW of new electrical generation capacity in the next 40 years, most of which could be supplied by RE. As El-Ashry puts it: *"Two billion people lack reliable energy, most of them in remote areas with little prospect of connecting to an electrical grid. If RE captures just 3% of the market in developing nations within 10 years, investments could exceed $5 billion a year"* [01GEF].[1]
6) A growing number of countries are introducing specific policies in support of RE, with biomass energy playing a central role. True, many decision makers still fail to take biomass energy seriously enough, partly because they greatly underestimated the full implications.
7) Environmental pressures will increase the price of fossil fuels as the cheaper sources are used up, and as the external costs are progressively incorporated into the final costs of energy, RE will be put into a more equal footing with fossil fuels.
8) Despite of the fact that some technologies have failed to live up to the commercial expectations, technology is evolving rapidly and the time-span is being reduced. Significant advances have been made in gasification, co-firing, biogas production, etc. In addition, agricultural productivity and improved management practices (that are key factors) are receiving much greater attention.
9) Modern applications of biomass energy such as electricity generation, ethanol fuels blended with gasoline, biodiesel, etc. are rapidly increasing. For example, in the US the use of ethanol fuel has been rapidly increasing in recent years; there are a growing number of other countries[2] (e.g. China, Colombia, India, Thailand) planning (or considering setting up) ethanol fuel programs.

A major challenge will be to tackle the problems posed by the traditional uses of bioenergy, e.g. low combustion efficiency and health hazards. For biomass energy to have a future it must provide people with what they want, i.e. cheap and convenient fuels such as lighting and power. As the WEC rightly puts it: *"Affordable modern energy services for everyone are a key to sustainable development and peace throughout the world"* [02WEC].

However, it is important to recognize that the modernization of biomass energy carriers cannot be confined to the production of electricity or liquid fuels, it must also include, for example, direct combustion such as improved cooking stove technology and better cooking practices. Many poor people may not be able to reap the benefits, say, of electricity generation purely on financial grounds.

Biomass energy is increasingly associated with environmental sustainability, contrary to the negative environmental perception in the past. The considerable potential of biomass as a carbon sinks and as a substitute for fossil fuels has long been recognized, e.g. in the Kyoto Protocol (articles 3.3 and 3.4). The IPCC estimates that between 60 and 87 GtC could be stored in forests between 1990 and 2050, or between 12-15% of the forecast fossil fuel emissions.

Overall, it seems that there is a gradual but strong move towards alternative energy sources resulting from a combination of factors that are putting in place many of the requirements needed for RE in general and biomass energy in particular to come to age. It is important to bear in mind that biomass energy is in

[1]) This appears very conservative by current trends.
[2]) The number of countries seriously considering the ethanol fuel option is growing by the day.

many ways intertwined with policies, socio-economics, technology advances and so forth that drives energy in general.

In the end, the market penetration of bioenergy will depend of a number of complex interactive factors such as political support, costs, subsidies, technology advances, cultural changes, socio-economic development, growing environmental concern, attitudes to global warming, etc. In the transportation systems, these interactive factors also have to take into consideration engine development, the diverse number of alternatives currently under investigation – e.g. bioethanol, biodiesel, biogas, hydrogen, synthetic fuels (both from fossil and biomass), gas (natural and from coal) –, availability and price of oil, distribution systems, etc., which make it even more complex and difficult to predict.

5.1.2 Introduction

Biomass energy (or bioenergy) is a broad and complex subject, and thus it is only possible to prepare an overview of the most important features. The potential of biomass energy is very large if proper policies are put in place. This is particularly the case with agro-forestry residues, currently an under exploited resource. In the longer term, dedicated energy forestry/crops will have a much greater role to play although this is a very complex subject, as explained in this section.

Currently, biomass energy continues to be the main source of energy in many developing nations, particularly in its traditional forms. However, modern applications are increasing rapidly both in the industrial and developing countries, representing 20-25% of the total biomass energy use. The over dependence on traditional biomass energy in some parts of the world has put considerable pressure on scare resources. The message is very clear: For biomass energy to have a future it must modernize to provide people with what they want, e.g. modern, clean and efficient energy such as electricity, lighting, water pumping, improved cooking stoves, liquid fuels (transportation sector) etc. in an environmentally sustainable manner.

A combination of environmental, social, energy, political and rapidly evolving technologies are opening up many opportunities for meeting the energy needs in a world that is increasingly conscious about the environment. Significant advances have already been made in many aspects of biomass energy production which are explained in this section. However, no attempt has been made to define such technologies as it is assumed that the reader will be familiar with such terms.

This section looks at the potential of biomass energy, particularly the utilization of residues and energy forestry/crops; current and future uses, traditional versus modern applications, technology trends in particular to combustion, cogeneration, co-firing, micropower generation, gasification and pyrolysis. The market for ethanol fuel for use in blend with gasoline is rapidly growing in the world largest fuel markets such as the USA and EU in addition to Brazil, while other countries are also considering setting up new programs; this is also the case with biodiesel which is rapidly increasing, particularly in the EU (particularly Germany) and USA. Biogas production and use is practiced in most countries, but only a handful (China, India, Nepal and Denmark) have a nationwide biogas program also briefly assessed. Charcoal production and its use is a major and growing activity in many developing nations, and for this reason the main implications are also discussed.

Biomass energy has major socio-economic impacts, particularly in rural areas of developing nations. The increase provisions of bioenergy could have important energy implications and additionally contribute to modernizing agriculture. Biomass energy is increasingly associated with environmental sustainability, and this is particularly so if the external cost of fossil fuels are internalized. The potential of biomass energy as a CO_2 abatement has been recognized in the Kyoto Protocol, and thus the benefits of a direct substitution of biomass for fossil fuel are briefly assessed. The rapid changes in the energy markets worldwide have major implications on bioenergy, which is also briefly discussed in Sect. 5.1.9. Finally, Sect. 5.1.11 suggests some policy recommendations and R&D needs.

The data for this section was originally compiled in 2000 and only partially updated until final publication in 2006. As renewable energy has become a very popular research field, the given figures are not in accordance with the actual developments anymore. Still, they indicate the general trend, and updated data can easily be obtained on the internet sites listed at the end of this section.

5.1.3 Biomass potential

Biomass resources are potentially the world's largest and most sustainable energy source comprising about 220 billion odt (or 4500 EJ) of annual primary production [99Hal1]. The annual bioenergy potential is about 2900 EJ (about 1700 EJ from forests, 850 EJ from grasslands, and 350 EJ from agricultural areas), though only 270 EJ could be considered available on a sustainable basis and at competitive prices. The problem is not availability but the sustainable management and delivery of energy to those who need modern energy services such as electricity.

Residues are currently the main sources of bioenergy and this will continue to be the case in the short to medium terms, with dedicated energy crops playing an increasing role in the longer term. This expected increase of biomass energy, particularly in its modern forms, could have a significant impact not only in the energy sector, but on the drive to modernize agriculture and rural development in many poorer countries.

5.1.3.1 Utilization of residues

Residues are a large and under-exploited potential energy resource and represent many opportunities for a better utilization. However, there are a number of important factors which need to be addressed when considering the use of residues for energy. First, there are many other alternative uses, e.g. animal feed, erosion control, use as animal bedding, fertilizer (dung), etc. Secondly, there is the problem of agreeing on a common methodology for determining what is and what is not a "recoverable residue" since estimates often vary by a factor of five. This is, among other things, due to variation in the amount of residue assumed necessary for maintaining soil organic matter, soil erosion control, efficiency in harvesting, losses, non-energy uses, disagreement about animal manure production in different parts of the world, etc.

5.1.3.1.1 Agricultural residues

There have been many attempts to estimate the energy potential of agricultural residues, but this is a very difficult task and only rough estimates are possible. For example, Smil has calculated that in the mid 1990s the amount of crop residues amounted to about 3.5 to 4 Gt annually, with an energy content representing 65 EJ, or 1500 Mtoe [99Smi]. [93Hal] have estimated that just using the world's major crops (wheat, rice, maize, barley, and sugarcane), and a 25% residue recovery rate could generate 38 EJ and off set 350 to 460 MtC/a. There is no doubt that a large part of the residues are wasted or handled inappropriately, causing undesirable effects from an environmental, ecological and food production viewpoint. For example, [91And], has estimated that over 2 Gt of agricultural residues are burned annually world-wide, while [99Smi] estimates are between 1.0 and 1.4 Gt, producing 1.1 to 1.7 Gt/a of CO_2 Worldwide, the generation capacity of agricultural residues (straw, animal slurries, green agricultural waste) is estimated to be about 4500 MWth.

5.1.3.1.2 Forestry residues

Forestry residues obtained from sound forest management do not deplete the resource base. On the contrary, the utilization of such residues can enhance and increase future productivity of forests. One of the difficulties when estimating the potential of residues available for energy use on a national or regional basis, with some degree of accuracy, is the lack of good data on total standing biomass, MAI, plantation density, thinning and pruning practices, current use of residues, etc. Recoverable residues from forests have been estimated to have an energy potential of about 35 EJ/a [94Woo], and these figures remain more or less valid today. A considerable advantage of these residues is that a large proportion is generated by the pulp, paper and saw mill industry and could be readily available. Currently, most of these residues are utilised to generate energy in these industries, but there is no question that the potential is considerably greater. In Brazil, for example, the pulp and paper industry generates almost 5 Mtoe of residues which are currently largely wasted. The estimated global generation capacity of forestry residues is about 10000 MWe.

The availability of residues for energy purposes could be significantly increased if practices in traditional forestry management, which are primarily concerned with timber production, were changed. For example, a shift to new, faster growing varieties would shorten the production cycles significantly and increase productivity.

5.1.3.1.3 Livestock residues

The potential of energy from dung alone has been estimated at about 20 EJ worldwide [94Woo]. However, the variations are so large that figures are often meaningless. These variations can be attributed to a lack of a common methodology which is the consequence of variations in livestock type, location, feeding conditions, etc. In addition, it is questionable whether animal manure should be used as an energy source on a large scale, except in specific circumstances. The reasons include:

- Manure may have a greater potential value for non-energy purposes (i.e. may bring greater benefits to the farmer if used as a fertilizer);
- It is a poor fuel and people tend to shift to other better quality biofuels whenever possible;
- The use of manure may be more acceptable when there are other environmental benefits. For example, the production of biogas and fertilizer reduces large surpluses of manure which, if applied in large quantities to the soil, represent a danger for agriculture and the environment, as is the case in Denmark;
- Environmental and health hazards which are much higher than for other biofuels [00Ros1].

For example, the use of poultry litter in combustion plants is of particular interest. Poultry litter is the material from broiler houses and contains material such as wood shavings, shredded paper or straw, mixed with droppings. As received, the material has a calorific value of between 9-15 GJ/t, with variable moisture content of between 20 and 50%, depending on husbandry practices. There is an installed capacity of about 150 MW worldwide (75 MW in the UK and over 50 MW in the USA) and it is growing rapidly. This represents a new economic, energy and environmental benefit of a resource that was mostly wasted in the past.

5.1.3.1.4 Energy forestry/crops

Energy forestry/crops can be produced in two main ways:

1) As dedicated plantations in land specifically devoted to this end;
2) Intercropping with non-energy forestry/crops.

Energy crops have a considerable potential for improvement with good management practices, as illustrated in Table 5.1.1. It is difficult to predict at this stage what the future role of specifically grown biomass for energy purposes will be. This is, in many ways, a new concept for the farmer which has to be fully accepted if large scale energy crops are to form an integral part of farming practices. It will also largely depend on the development of carbon credits. [93Hal] estimated that as much 267 EJ/a could be produced from biomass plantations alone, requiring over a billion hectares. However, these predictions were largely based on the assumption that energy plantations will be on degraded lands; this was questioned by recent studies since a key to producing low-cost energy forestry/crops is the land base and quality of sites, which are the major determinants of the total feedstock cost.

There are currently two main approaches for energy plantations:

1) Industrial countries, where there is surplus land (excess and underutilized) not needed for food production. For example, USA farmers are paid not to farm about 10% of their land, and over 30 Mha of cropland have been set aside to reduce production or conserve land; a further 43 Mha of cropland have high erosion rates and further 43 Mha have wetness problems. This land could be eased with a shift to various perennial energy crops. In the EU, up to 15% of arable farmland can be "set-aside" although the percentage tends to vary over the years.
2) In tropical developing countries, the prime candidates are mainly cleared and degraded lands, forests lands occupied by low value commercial species, etc.

Despite the considerable potential for energy plantations in tropical countries, the greatest prospects, at least in the medium term, would be in the industrial countries due to the availability of land, capital, skills, greater environmental pressure, etc.

Recent studies show that plantations aimed to generate electricity can be financially viable when local conditions are favorable and the costs of conventional fuels are high. Costs for energy forestry/crops vary from 1.90-2.80 $/GJ/ha/a in the USA (10-15.5 t/ha/a); 4.0 $/GJ/ha/a in Sweden (15 t/ha/a); 0.97-4.60 $/GJ/ha/a in Brazil (3-21 t/ha/a); 0.42-1.18 $/GJ/ha/a in Philippines (15.4 t/ha/a), see also http://bioenergy.ornl.gov/reports/fuelwood/chap5.html.

Table 5.1.1. Global data on current and feasible biomass productivity, energy ratios and energy yields for various types of crops and conditions [00Mor], [99Hog].

	Energy out-put-input ratio	Yield [dry/t/ha/a]	Net energy yield [GJ/ha/a]
SRC e.g. willow & hybrid poplar (USA, Europe)			
- Short term	10:1	10-12	180-200
- Long term	20:1	12-15	220-260
Tropical plantations			
- No genetic improvement & fertilizer use & irrigation	10:1	2-10	30-180
- Genetic improvement & fertilizer use	20:1	6-30	100-550
- Genetic improvement, fertilizer & water added	-	20-30	340-550
Miscanthus/switchgrass			
- Short term	12:1	10-12	180-200
- Long term	20:1	12-15	220-260
Sugarcane & sugarbeet			
- Sugarcane (Brazil)	18:1 [1])	15-20	250-300
- Sugarbeet (W. Europe)			
- Short term	10:1	10-16	30-100
- Long term	20:1	16-21	140-200
Rapeseed including straw (W. Europe)			
- Short term	4:1	4- 7	50- 90
- Long term	10:1	7-20	100-170
Wood from commercial forests	20/30:1	1- 4	30- 80

[1]) Include energy expenditure in transport and processing of sugarcane to ethanol assuming the final product is ethanol only.

It seems that large-scale energy plantation predictions are unlikely to be achieved; and a more likely scenario would be closer to 300 Mha. There are various reasons:

- Degraded land is less attractive than good quality land due to higher cost and lower productivity;
- Capital and financial constrains particularly in developing countries;
- Cultural practices, mismanagement, perceived and potential conflict with food production, population growth (see Sect. 5.1.7.3);
- Productivity will have to increase far beyond what may realistically be possible;
- Increasing desertification problems and potential impacts of climate change in agriculture.

The combination of all these factors will severely limit a large-scale development of dedicated energy plantations.

An issue which has received little attention until now is the potential international trade on bioenergy. If large-scale energy plantations become a reality, this could be a new major economy activity in some regions (see www.bioenergytrade.org)

It would be more realistic to concentrate on the use of agro-forestry residues and some highly productive crops such as sugarcane. For example, in Brazil it has been possible to increase energy production from 3750 MJ per ton of sugarcane to 4700 MJ in just over a decade with good management practices. This means that a sugarcane plantation of 100 ton/ha can generate 480 GJ/ha/a [00Mor].

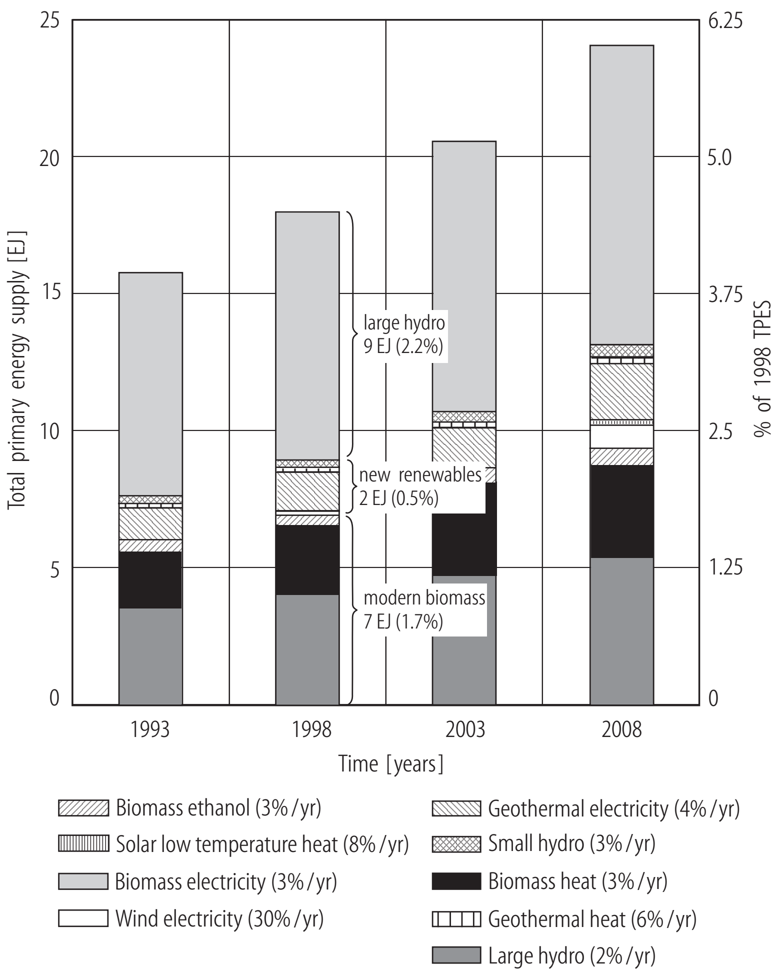

Fig. 5.1.1. World renewables – total primary energy supply (TPES) and shares. Projections upon yearly rate of increase by source, 2.89% for renewables and 3.73% for new renewables [02Gol].

The potential of sugarcane as a global crop is significantly larger that is has been realized so far. For example, 143 Mha of new sugarcane, converted to energy purposes, could generate 26 Mboe/day of ethanol and 10000 TWh/a of electricity by 2020 [02Mor]. This is a feasible alternative taking into consideration that sugarcane is produced in 102 countries, which allows an increase of production without any major investment. It assumes that new technologies and modern management practices will be applied (see Table 5.1.2). Due to low sugar prices, the sugarcane industry is desperately trying to diversify and find alternative uses for sugarcane and by-products.

During the past decade many initiatives have been taken to reforest around the globe e.g. over 40 Mha have been planted in developing countries – two-thirds in community woodlots – and smallholdings to provide industrial wood, environmental protection and energy. For example, China is planning 13.5 Mha of plantations by 2010; in the US, about 50000 ha of agricultural land have been converted to woody plantations; India has a program to reforest 1.2 Mha/a. However, little experience still exists with large-scale energy plantations. Exceptions are eucalyptus for charcoal production, ethanol from sugarcane in Brazil and willows for heat and power generation in Sweden. Nevertheless, all these cases have followed traditional agricultural and forestry practices [99Hal2].

Table 5.1.2. Global energy potential from sugarcane, year 2020 [02Mor].

Country	Potential area [Mha]	Fuel		Electricity production		Fuel & electricity production	
		[EJ]	[Mboe/day]	[TWh/a]	[EJ]	[EJ]	[Mboe/day]
Brazil	20	6.60	3.67	1400	9.8	16.40	9.12
USA	10	3.30	1.84	700	4.9	8.20	4.56
India	10	3.30	1.84	700	4.9	8.20	4.56
China	10	3.30	1.84	700	4.9	8.20	4.56
Mexico	4.8	1.58	0.88	336	2.35	3.94	2.19
Central America	4.8	1.58	0.88	336	2.35	3.94	2.19
South America	16	5.28	2.94	1120	7.84	13.12	7.30
South Asia	16	5.28	2.94	1120	7.84	13.12	7.30
Australia	16	5.28	2.94	1120	7.84	13.12	7.30
Africa	16	5.28	2.94	1120	7.84	13.12	7.30
Others	20	6.60	3.67	1400	9.8	16.40	9.12
TOTALS	143.6	47.36	26.35	10052	70.4	117.72	65.50

World oil and electricity demand	Oil [Mboe/day]	Electricity [TWh/year]
Total 2000 [1])	39	13000
Total 2020 [1])	68	22000

[1]) Source: [00EIA].

5.1.4 Current and future uses of biomass energy

Since the early 1990s there has been an increasing interest in biomass for energy, demonstrated in a large number of energy scenarios which show biomass as a major potential source of energy in the 21st century. [01Hoo] analyzed 17 of such scenarios, classified into two categories:

- Research Focus (RF),
- Demand Driven (DD).

The estimated potential of the RF varies from 67 to 450 EJ for the period 2025-2050, and that of the DD from 28 EJ to 220 EJ during the same period. The share of the total final energy demand lies between 7 and 27%. Figure 5.1.1 summarizes the estimated contribution of RE from 1993 through 2008 according to IEA predictions. It should be noted that the figures on biomass seem rather conservative.

A major difficulty in estimating bioenergy, particularly in its traditional forms, is the large discrepancies caused, among other things, by

- poor quality of the data available;
- a considerable amount of bioenergy forms an integral part of the informal economy, hence it hardly enters official statistics;
- lack of long term good quality data;
- the tendency of conventional energy agencies to downgrade the role of biomass energy.

It is difficult to separate biomass energy from other RE as they are in many ways interrelated and influenced by the same factors such as energy, politics, socio-economics, technology, etc. For example, wind energy has been growing over 35% annually for the past five years and in 2001, the installed capacity worldwide-reached 24 GW – and a further 5 to 9 GW are expected to be added in the next few years[3]. The EU is the world leader with 4.5 GW, followed by the USA with 1.7 GW. Over the past two decades the cost of generating energy from wind has dropped by over 80%. However, high installation costs and increasing local resistance (i.e. noise and visual impacts) in many industrial countries may significantly limit this option in the future. The world market in PV in 1999 was about 200 MW, but it may exceed 1.8 GW in 2010. However, PV and wind power are highly restricted (i.e. often this power may not be available for more than 50% of the time, see Chap. 3 and Sect. 4.2) unlike biomass which is available all the time.

Traditional and modern biomass energy is intertwined and difficult to distinguish. Recent evidence also shows that bioenergy is used by both low and high income groups in many parts of the world and that modern use of biofuels are complementary to traditional fuels in many cases [97FAO].

5.1.4.1 Traditional applications of bioenergy

Traditional uses of biomass have been estimated to lie between 700 and 1200 Mtoe, depending on the sources. These are rough estimates since a large part of traditional uses are at the core of the informal economy and never enter the official statistics as already indicated above.

Traditional biomass energy, particularly as used in most developing nations, has been called “the poor man’s fuel” – or better to say “the women & children’s fuel” since it is women and children in rural areas who devote considerable amount of time to collect the daily fuelwood needs. Traditional uses of biomass energy in developing countries still represent the bulk of energy. The countries that rely more on biomass energy are Burundi, Ethiopia, Mozambique, Nepal, Rwanda, Sudan, Tanzania, and Uganda, all of which derive about 90% of their energy from biomass.

The use of biomass energy in its traditional forms can potentially cause serious energy and environmental problems because of the low combustion efficiency, cultural factors and poor management practices, although this is not necessarily true in all cases. Energy efficiency varies considerably e.g. from

[3]) The total installed wind power capacity is expected to surpass 50 GW by mid 2010.

about 2-20% in developing countries, compared to 65-80% (or even 90%) in some industrial countries. But, as a result of this low efficiency, it is an enormous waste of resources. Additionally, traditional bioenergy can not provide the type of modern energy applications most people want. Thus, the clear message is that bioenergy production and use must be modernized.

Traditional biomass energy use would probably continue to grow in absolute terms in many poor countries, at least in the short to medium terms, mainly due to population growth and lack of purchasing power of the poor for modern services. Indeed, the IEA predicts that by 2030, 2.6 billion people in developing countries will continue to depend on biomass for cooking and heating [02IEA].

5.1.4.2 Modern applications of bioenergy

It is estimated that approximately 20-25% of biomass energy is used in modern applications and is increasing rapidly both in industrial and developing countries. The total estimated installed capacity of biomass-based electrical power worldwide varies considerably, ranging from 20 GWe [00Tur] to about 108 GWe or just over 4% of all electricity generation capacity [00Koo], [99Hor]. These differences are partly due to the existence of many small applications.

For biomass energy to have a future, it must be able to provide people with things they want e.g. electricity, improved cooking stoves, etc. There are enormous pressures on resource utilization, environment, etc, for a better use of scarce resources which can only be met by more efficient conversion technologies and better management practices. Modern applications simply mean clean, convenient, efficient, reliable, sustainable, economically and environmentally sound applications. Many mature technologies that can meet such criteria already exist and are not necessarily more expensive than fossil fuels if all costs are internalized [00Ros1].

The modernization of biomass embraces a range of differing technologies ranging from combustion, gasification to pyrolysis. There are many modern applications including

- household applications, e.g. improved cooking stoves, use of biogas, ethanol;
- small cottage industrial applications, e.g. brick-making, bakeries, ceramics, tobacco curing;
- large industrial applications, e.g. CHP, electricity generation;
- transport uses, e.g. ethanol and biodiesel as direct substitutes to oil.

One of the most promising areas for modernization of biomass energy in large industrial scale is in the sugarcane industry as demonstrated by various studies (see Sect. 5.1.5.3). However, much will depend on the development of other RE and fossil fuels prices.

There are many countries around the world which have introduced specific policies in support of RE. For example, the EU has recently unveiled its proposals for RE, aimed at doubling the proportion of RE to the primary energy supply from 6 to 12%. This will largely be accomplished by increasing the share of RE generated electricity from 14 to 22% by 2010. In the case of transportation sector, the EU could be using as much as 20% of biofuels as transport fuel by 2020 (see Sect. 5.1.6.1.3).

As an example, Austria had, at the end of 1997, 359 biomass plants with an output of 483 MWe and over 0.6 million homes were heated by bioenergy. A program of research has permitted an increase of combustion efficiencies from 60 to almost 90% in the past decade alone.

In 1986 the Danish government embarked in a program of RE aiming at providing 35% of the country's primary energy by 2030. Today the country has 150 heating plants operating on woody biomass with about 450 MWe; there are about 80000 wood-based and straw-based boilers, plus a further 200 MWe of CHP. Denmark is also a world leader in large-scale biogas technology, see Sect. 5.1.6.3.4.

In 1998 Finland's energy consumption was 31 Mtoe of which about 25% was RE, mostly biomass. Finland's 1999 Action Plan for RE foresees an increase of at least 50% by 2010. Spain's new energy plan foresees a tenfold increase in energy generated from biomass from the current 1139 to 14000 GWh by 2012.

In the USA, about 4% of the primary energy comes from biomass; there is a biomass-based capacity of about 10 GW (based on mature direct combustion technology alone); see Sect. 5.1.6.1.2. Even Japan plans to obtain 3% of its primary energy supply from RE by 2010.

In many developing countries, considerable efforts are also being made to develop new RE technologies. Brazil is a world leader in the industrial applications of biomass energy [00Ros2], and India has launched one of the world's largest cogeneration programs based on bagasse (358 MW already commissioned and a further 389 MW under construction [02Bha]). India's Five Year Plan foresees a 24 GW from RE by 2012, i.e. about 10% of the country's total power generation capacity[4]. In Indonesia about 178 MW of biomass based power is in operation plus a further 82 MW by 2003 [99Tim]. There are also large biogas programs in China, India, Nepal, etc., see Sect 5.1.6.3.

China's RE plan for 1996-2010 includes 13.4 Mha of fuelwood plantations, 4 billion m^3 of biogas to supply for 12.35 million households plus 3 billion liters of ethanol. In the Philippines, the government is planning to increase RE technologies-based power plants from 1.4 GW in 19960 about 10.3 GW in 2025 (about 10% of the total installed capacity) of which biomass will be a major source. It has been estimated that over 210 million improved cooking stoves have been distributed in various Asian countries, over 177 million in China alone [99Tim].

These are just a few examples of the modernization drive of biomass energy in both industrial and developing countries. This is largely due to the formulation of specific policies and strategies aimed at the development and promotion of RE. Generally, though, biomass energy still does not receive a corresponding share of support if compared with its energy role, particularly when it comes to R&D.

5.1.5 Technology trends

The pace of technological advances is opening up many new opportunities for RE in general and biomass-based high quality fuels in particular, considered just a few years ago as a long term prospect. Some advances in bioenergy production and use include

- improved integrated biomass gasifier/gas turbine (IBGT) systems for power generation;
- gas turbine/steam turbine combined cycle (GTCC);
- circulating fluidized bed (CFB), integrated gasification combined cycles (IGCC), cogeneration, co-firing;
- improved techniques for biomass harvesting, transportation and storage;
- gasification of crop residues;
- biodiesel technology;
- continuous fermentation (simultaneous saccharification and fermentation);
- anaerobic fermentation;
- use of bacteria;
- heat recovery in the distillation process;
- improved processes (acid and enzymatic hydrolysis) to obtain ethanol from cellulosic material;
- better use of by-products (bagasse which is increasingly used for electricity cogeneration);
- production of methanol and hydrogen from biomass, fuel cell vehicle technology, etc.

Of course, despite these advances there have been many disappointments, as some of these technologies, particularly gasification and hydrolysis technology, have failed to meet the expectations.

Currently biomass-fuelled power plants are small, usually under 100 MW, mostly because these plants operate attached to waste mills such as pulp and paper and sugarcane mills. Large biomass power plants are unlikely in the near future because of the logistics for supply, e.g. they will need large amounts of biomass which will have to be transported from long distances which will increase transport costs considerably. An immediate answer may be co-firing with other raw materials, particularly coal, once some of the technical problems have been solved. It is estimated that as much as 348 GJ/ha/year of electricity could be obtained using advanced technologies. Some of the most promising examples are briefly described below.

[4]) The 10000 MW plan to generate electricity from RE, to be used mostly to provide electricity to 18000 villages by 2012 and costing $11.8 billion, is a good example.

5.1.5.1 Combustion

Combustion technologies play a major role throughout the world, producing about 90% of the energy from biomass. Combustion technologies convert biomass fuels into several forms of useful energy e.g. hot air, hot water, steam and electricity. The simplest combustion technology is a furnace that burns biomass in a combustion chamber. A biomass-fired boiler is a more adaptable technology that converts biomass to electricity, mechanical energy or heat. Biomass combustion facilities that generate electricity from steam-driven turbine generators have a conversion efficiency of 17-25%, cogeneration can increase this efficiency to almost 85%. Large-scale combustion systems use mostly low-quality fuels, while high-quality fuels are more frequently used in small application systems.

Commercial and industrial combustion plants can burn many types of biomass ranging from woody biomass to Municipal solid waste (MSW). Combustion technology still needs to be optimized. Fundamental breakthroughs are not expected, but rather small improvements considering cost reduction, increase of fuel flexibility, lower emissions, flue gas cleaning, formation of particulates, multi-component and multi-phase systems, NO_x and SO_x formation, maximum safety and simplification of the operations. This is particularly more pressing if competitiveness with gasification and pyrolysis is to be maintained as these technologies are being developed. There are various industrial combustion systems available which, broadly speaking, can be defined as fixed-bed combustion (FxBC), fluidized bed combustion (FBC) and dust combustion (DC), see Table 5.1.3.

5.1.5.2 Cogeneration/CHP

Enthusiasts of cogeneration forecast an increasing role in power supply stimulated by the changes taking place in the electricity sector. Cogeneration (known under various names such as CHP, distributed generation, on-site generation, small-scale generation, district energy systems, etc) is not new; in fact, it can be traced back for centuries. It comprises at least four different thermodynamic processes of combined heat and power production:

1) Use of air as a medium;
2) Use of steam;
3) Utilization of heat rejected from a separate combustion process;
4) Use of thermodynamics as those found in a fuel cell.

Table 5.1.3. Large-scale combustion systems (compiled from material at www.ieabioenergy.com).

System	Remarks
FxBC - grate furnaces - underfeed stokes	Grate furnaces are better for burning biomass fuels with high moisture content, different particle sizes and high ash content. Usual capacity goes up to 20 MWth. Underfeed stokes represent a cheap, safe technology for small and medium scale systems up to 6 MWth.
FBC [1]) - bubbling (BFBC) - circulating (CFBC)	Biomass fuels are burned in a self-mixing suspension of gas and solid bed material in which air for combustion enters from below. FBC plants are better suited for large-scale applications, 30+ MWth. For smaller plants FxBC are usually more cost-effective.
DC	A mixture of fuel and primary combustion air is injected into the combustion chamber. DC is suitable for biomass fuels available in small dry particles such as wood dust. Fuel-feeding needs particular control due to the explosion-like gasification process of the biomass.

[1]) Categorization depending on the fluidization velocity.

In the biomass energy sector this option seems mostly limited to the utilization of residues in a small scale, e.g. forestry and sugarcane bagasse. These technologies offer the potential for a much cleaner environment. Also, for the two billion of people who remain without electricity, small-scale power may represent one of the best hopes. The trend toward more open, decentralized, competitive electricity system brings many advantages for the introduction of small-scale power [00Min].

CHP is being actively promoted in many countries not only for its potential energy benefits, but also because it is considered an effective instrument for cutting CO_2 emissions in the short term: In the EU for example, the potential of cogeneration for reducing CO_2 has been estimated at 150 $MtCO_2$/a [00Min].

CHP plants, in the range of 30 kW to 30 MWe, are an established technology that is cost competitive with conventional power. CHP is increasingly installed outside its traditional areas, e.g. horticulture, micro-turbines, domestic scale, fuel cells, etc. But the greatest potential for growth seems to be micro-CHP as a direct replacement for conventional gas boilers, particularly obsolete central heating boilers. The micro-CHP concept may be able to use a mixture of fuels, e.g. natural gas and biomass.

The micro-CHP plant is still an emerging technology with the first units currently on commercial trial. Micro-power technologies already use RE sources in small gasifier applications, mostly the fixed down-draft gasifier coupled with IC engine. The Stirling engine may also become a suitable economic biomass combustion option for small-scale power production around 30 kWe. However, the most important factors that will affect CHP may be fuel flexibility[5] and control. Table 5.1.4 summarizes efficiencies and costs of small-scale generation technologies.

Trigeneration, based on gasification of crops residues and the use of micro-turbines for CHP, is a new concept that could also potentially bring major benefits to many rural areas. Village-scale trigeneration is said to offer a major promise in reaching multiple economic and environmental goals for rural development simultaneously. For example, the potential of trigeneration based on surplus residues in China alone has been estimated at 22 GWe [00Hen]. Other wood-based technologies which are rapidly developing include woodchip boilers, two-stage combustion log boilers, catalytic and two-stage combustion stoves, wood pellet boilers, etc.

Table 5.1.4. Summary of electrical efficiencies and investment costs of small-scale biomass conversion technologies [02Sim].

Technology	Power output [MWe]	Electrical efficiency range [%] (based on LHV)	Investment costs [$/kWe]
Gasifier or bio-oil/ICE	0.05 - 3	25-30	800-1200
Boiler/Steam turbine	0.5 - 1	5-10	4800-2900
	1 - 5+	10-20	2700-1700
	5 - 10+	15-30	2300-1600
Boiler/Steam engine	0.01 - 1.5	5-25	7000-2000
Combustion/Stirling engine	0.01 - 0.15	15-30	4800-1600
Indirectly fired gas turbine	0.3 - 3	20-24	5000-2600
Directly fired gas turbine	5 - 10+	25-30	3000-1300
Gasifier/Micro-turbine	0.025 - 0.25	20-30	1300-1000

[5]) Fuel flexibility is a major advantage of CHP. In summer 2002, one the world most efficient multi-fuel CHP plant that burns natural gas, oil, wood pellets and straw with an efficiency of up to 94% was opened in Denmark.

5.1.5.3 Cogeneration of electricity from sugarcane bagasse

As already indicated, cogeneration is particularly promising in the sugarcane industry. A policy of deregulation, privatization and restructuring the electricity market, together with pressure from the sugarcane industry to modernize and diversify, should stimulate a large-scale cogeneration.

Approximately 350 Mt of bagasse are produced worldwide, mostly used as fuel in the sugar factories (plus a further 350 Mt of tops and leaves, currently mostly wasted). Other than for generating heat and power, most of the bagasse is used for pulp and paper, board, animal feed, etc. Sugar producers have been using bagasse to raise steam for on-site processes for centuries, but very inefficiently. However, more recently many sugarcane mills have become more energy self-sufficient and some are selling electricity to the national grids. Interest in cogeneration has increased considerably in many sugarcane producing countries of which Brazil, India, Thailand and Mauritius are good examples. A study by Larson & Kartha showed that in developing countries as a whole "excess" electricity (i.e. above and beyond the electricity needed to run the sugar/ethanol mill) could amount to 15-20% of the projected electricity generation from all sources in such countries in 2025, i.e. about 1200 TWh/a out of a total production of over 7100 TWh [00Lar]. Moreira found a potential of 10000 TWh/a from 143 Mha of sugarcane (Table 5.1.2) [02Mor].

In Brazil, the commercial cogeneration potential from all sugarcane residues has been estimated at 9 to 10 GW of which 2-3 GW could be commercially competitive using conventional technology without subsidies. The current installed capacity is about 1 GW [02Ros1]. Bauen has estimated the total energy content of sugarcane residues in Brazil about 1634 PJ [99Bau]. The potential surplus electricity generated from sugarcane residues (bagasse, tops and leaves) during and outside the harvesting season has been calculated at 180 kWh_e/tC and 234 kWh_e/tC, respectively. Surplus electricity from high pressure boilers coupled to condensing-extraction steam turbines (CEST) is estimated to be between 80 and 100 kWh_e/tC, considering only bagasse use during the milling season, and about 220 kWh_e/tC if harvest residues are considered for year around operation. The cost of harvest residues delivered to the plant is estimated to range approximately between 0.17 and 0.56 $/GJ ($ value in 1999) [99Bau].

In India, the potential for cogeneration from the country's 430 sugarcane mills has been estimated between 2.8 and 5.1 GW. Cogeneration projects already commissioned or being implemented total about 750 MW [02Bha].

5.1.5.4 Co-firing

Co-firing is potentially a major option for the utilization of biomass particularly in large-scale if some of the technical, social, and supply problems can be overcome satisfactorily. Co-firing of biomass with fossil fuels, primarily coal or lignite, has received considerable attention. In the USA, for example, tests have been carried out in over 40 commercial plants demonstrating that co-firing of biomass with coal has the technical and economic potential to replace at least 8 GW of coal-based generation capacity by 2010 and as much as 26 GW by 2020, which could reduce carbon emissions by 16-24 MtC. Since large-scale power boilers range from 100 MW to 1.3 GW, the biomass potential in a single boiler ranges from 15 to 150 MW [97ORN].

Biomass can be blended with coal in differing proportions, ranging from 2 to 25+%. Extensive tests show that biomass could provide, on average, about 15% of the total energy input with only feed intake systems and burner modifications. Also, preparation of biomass to an appropriate size (i.e. >1/4 inch and with a moisture content of less than 25%), can be achieved with existing technologies [97ORN]. The main advantages of co-firing include:

- relatively small investment is needed compared to a biomass-only plant (i.e. minor modification in existing coal-fired boiler);
- high flexibility in arranging and integrating the main components into existing plants (i.e. use of existing plant capacity and infrastructure);
- favorable environmental impacts compared to coal-only plants;
- potentially lower local feedstock costs (i.e. use of agro-forestry residues and energy crops if present productivity can be increased significantly);

- waste disposal benefits (i.e. the use of biomass-based wastes and RDF will also reduce the need for land-based waste disposal);
- potential availability of large amounts of feedstock (biomass/waste) that can be used in co-firing applications if supply logistics can be solved;
- higher efficiency for converting biomass to electricity compared to 100% wood-fired boilers. For example, biomass combustion efficiency to electricity would be 33-37% when fired with coal);
- planning consent is not required in most cases or will be relatively easy compared to a new plant.

Currently, about 40% of the world's electricity is produced by coal-fired power stations in over 80 countries. IEA data indicate that there is about 100 GWe of coal-fired plant capacity older than 40 years rising to as much as 500 GWe within the next 20 years [01IEA]. A considerable proportion of these plants would benefit by deploying more co-utilization of coal and natural gas and biomass, which has the greatest potential for reducing GHG. Globally, co-firing with biomass could be deployed on an installed plant capacity of 100 GWe. A European study found that half of the costs of CO_2 reduction for CHP based on either coal or biomass consisted of exchanging old coal-fired power stations with new clean technology. Co-firing in existing old plants offers many advantages for large-scale gasification (see www.iea-coal.org.uk).

A range of technology components can be used in co-firing of biomass/waste with coal which can be divided into three main types [02Kno]:

- Direct co-combustion;
- Indirect utilization;
- Handling systems.

Direct combustion includes stoker-fired combustion systems (e.g. static grates, chain graters, etc.), cement kilns, FBC (atmospheric FBC, bubbling fluidized bed boilers (BFBB), circulating FBC, pressurized FBC, cyclone furnaces, and pulverized fuel boilers (PFB)). Indirect combustion technologies used in co-firing include gasification systems, i.e. integrated gasification combined cycles (IGCC), topping cycles, i.e. air blown gasification (ABG), pyrolysis, carbonization and hybrid systems. Biomass handling systems, collection logistics and infrastructure, constitute a large portion of the capital investment and operating costs of a biomass power plant. Requirements and costs will depend of many varying factors, e.g. type of biomass to be harvested and transported, feedstock preparation requirements of the conversion technology, storage, feeding equipment, etc.

The technical feasibility of biomass co-firing is largely proven although problems still remain:

- Effects on boiler efficiency;
- Fuel feed control;
- Combustion stability;
- Fuel delivery, etc.

The costs for implementing biomass co-firing vary considerably from site to site, since they are influenced by a large number of factors including biomass yield, storing, shipping, type of boiler burner modification, etc. In the USA, the costs are expected to be in the range of 100-700 \$/kW of biomass capacity. A 100 MW coal plant with 10% biomass blend would require about \$1.8 million. The biomass cost should be around 9 \$/t; above this value, biomass would have to be subsidized [97ORN].

The environmental advantages of co-firing biomass/waste with fossil fuels are not fully established yet, but it is generally accepted that there are many of them compared to fossil-fuel-only plants. For example, recent biomass co-firing tests at several coal-fired power plants in the USA have demonstrated that 5% of biomass reduces NO_x by 10%, co-firing residues biomass by 15% reduces the GHG and net energy consumption of the average coal system by 18% and 12%, respectively [97ORN]. In 2001, Mann and Spath carried out a number of LCA studies to determine the environmental benefits and drawbacks of co-firing [01Man]. The studied systems were:

- biomass (IGCC) using energy crops,
- direct-fired biomass power plant using biomass residues,

- pulverized coal (PC) boilers,
- biomass waste with coal and
- natural gas combined cycle plants.

Their results *"demonstrate quite clearly that biomass power provides significant environmental benefits over conventional fossil fuel-based power systems"*.

There are still various non-technical problems, e.g. barriers, risks and uncertainties associated with co-firing of biomass/waste with fossil fuels including

- concerns about security of supply and quality of the raw material (i.e. seasonal nature, long-term storage, lack of experience in dealing with biomass on a large industrial scale, biomass resource constraints, etc). Industrialists are particularly concerned about the feasibility of supplying large amounts of biomass quickly, which can be a major sticking point that needs to be overcome;
- public perception and planning regulations in some countries;
- potential health hazards (i.e. fungal spores in wood and increased risk of fire);
- lack of financial incentives and current procedures that need to be simplified;

The international market for co-firing of coal and biomass/waste has been estimated to range from $10 billion to $190 billion annually [98ETS]. In the medium term a potential of 265 plant retrofits has been considered feasible in 20 of the world's largest markets, totaling about 8 GW of biomass-fired capacity and valued approx. at $38 billion.

In summary, despite the fact that some technical, economic and supply problems still remain to be solved, co-firing of biomass, particularly with coal, is one of the most economically and environmentally attractive option for large-scale use of biomass. As Baxter puts it: "*while several potentially severe issues associated with co-firing biomass exist, recent work indicates all issues are resolvable through proper choices of fuels, boilers, and operating conditions*" [02Bax].

5.1.5.5 Gasification

Gasification is one of the most important ongoing RD&D areas in biomass for power generation as it is the main alternative to direct combustion. Gasification is an endothermal conversion technology where a solid fuel is converted into a combustible gas. The product gas consists of carbon monoxide, carbon dioxide, hydrogen, methane, trace amounts of hydrocarbons, water nitrogen and various contaminants such as char particles, ash and tars. The importance of this technology relies on the fact that it can take advantage of advanced turbine designs and heat-recovery steam generators to achieve high energy efficiency.

Gasification technology is not new, the process has been used for almost two centuries (in the 1850s, much of London was illuminated by "town gas", produced from the gasification of coal). This technology is close to commercialization with over 90 installations and over 60 manufactures around the world. Currently only gasification for heat production has reached commercial status. The best known are the Bioneer, PRM Energy, Foster Wheeler and Lurgi Umwelt fixed-bed, updraft (FBU) type [02Kno]. There are many excellent reviews of gasification, e.g. [97Kal], [98Kal], [00Wal]. The main attractions of gasification are

- higher electrical efficiency, e.g. 40+% compared with combustion 26-30%, while costs may be very similar;
- the possibility for substantial new developments such as advanced gas turbines, fuel cells, etc.;
- possible replacement of natural gas or diesel fuel use in industrial boilers and furnaces;
- distributed power generation where power demand is low;
- displacement of gasoline or diesel in an internal combustion (IC) engine.

Interest in gasification increased substantially in the 1990s, again driven mostly by concerns about the use of fossil fuels and their possible impacts on climate change. At the same time there is also a worldwide growing interest in developing new and advanced coal technologies that cut costs and reduce pollutants. Among the options being considered are super-critical pulverized coal steam plants (SPCSCP), and

IGCC with an improved efficiency of 43-45% for current designs (50% for new design). These advances reduce costs and thus make the biomass-based option less attractive. Coal is the world most abundant source of energy and thus, the main challenge is to find environmentally more acceptable alternatives.

Despite many efforts, gas cleaning still constitutes one of the most serious technical and economic barriers in gasification. This is a difficult issue because it depends of many varying factors such as feedstock characteristics, type of used gasifiers and ultimately cost of a particular option. Substantial RD&D programs have been carried out in the past two decades in many countries. For example, India has installed 1757 small units by the end of 2001 with an installed capacity of about 43 MW [02Bha]. It is one of the most comprehensive biomass gasification programs in the range of small to medium scale gasifiers in the world. The major focus has been the use of modified diesel engines to run in a dual-fuel mode.

Although gasification has not reached a commercial status yet, it is widely accepted that, if fully commercialized, it will bring many environmental and economic benefits, i.e. could reduce nitrogen oxides, sulphur dioxide and other pollutants emissions by 80 to 90% (see www.afandpa.org/).

5.1.5.6 Pyrolysis

The main advantage of pyrolysis over gasification is a wide range of products that can potentially be obtained, ranging from transportation fuels to chemical feedstock (e.g. adhesives, organic chemicals, and flavoring) that offer good possibilities for increasing revenues. Considerable amount of research has gone into pyrolysis in the past decade in many countries; see [97Kal]. Any form of biomass can be used (over 100 different biomass types have been tested in labs around the world), but cellulose gives the highest yields at around 85-90 wt-% on dry feed. Liquid oils obtained from pyrolysis have been tested for short periods on gas turbines and engines with some initial success, but long-term data is still lacking (see www.pyne.co.uk).

Pyrolysis of biomass generates three main energy products in different quantities: coke, oils and gases. Flash pyrolysis, a high temperature process (450-600°C) in which biomass is rapidly heated in the absence of oxygen, gives high oil yields, but still needs to overcome some technical problems needed to obtain pyrolytic oils. However, fast pyrolysis, a thermal technique used to break down larger macromolecules into simpler monomers, is one of the most recently emerging biomass technologies used to convert biomass feedstock into higher value products.

In addition to the potentially large value-added products from pyrolysis, there are also environmental attributes and the benefits arising from marketable green certificates by displacing fossil fuels. For example, DynaMotive is commercializing its BioOil as a clean burning fuel that can be used to replace fossil fuels in a variety of applications ranging from transport, CHP generation, boilers and kilns [01DYN].

5.1.6 Liquid and gaseous fuels

During the 1970s and early 1980s there was a considerable interest in ethanol fuel and biogas due to high oil prices, but interest subsided considerably in the late 1980s and 1990s as oil prices declined in real terms. However, since the late 1990s interest has picked up again largely for environmental and social reasons helped by changes in the international energy market. The forces pushing for renewable transport fuels vary from country to country. However, there are some common features:

- Environmental concern with clean air is a social and political priority throughout the world;
- Increasing dependency on imported energy supply is also a general concern;
- Social and economic pressures, particularly from farmers.

Many countries regard alternative fuels not only as environmentally clean, but also as an effective tool for socio-economic development, particularly in rural areas. This is why many governments currently support RE either through legislation or tax incentives or both. Support for a particular fuel is dictated by the specific circumstances of a country or region.

5.1.6.1 Ethanol fuel

The countries that historically pioneered ethanol fuel production in large scale were Brazil, followed by the US and at much smaller scale by Kenya and Malawi. Currently world production of ethanol (all categories) is estimated to be between 35 and 40 billion liters (taking into account possible underreported production due to high duty taxes), the majority of which is fermentation alcohol. The current estimate for the installed capacity of fuel ethanol (2002) is about 29 billion liters (2002), or approx. 23.2 Mt, while the total production is approximately 25.5 Bl (see Table 5.1.5). Historically, ethanol has provided an alternative to gasoline and the automotive pioneers, e.g. Nikolaus Otto and Henry Ford, considered ethanol as the fuel of the future.

Approximately 3 billion liters of ethanol per year are currently traded, with Brazil and the USA being the main exporters and Japan and EU the main importers. Japan is currently considering blending ethanol with gasoline, and if this is to become a reality, it could become a major market[6]. The EU is also a potential major market if its ambitious biofuel targets are to be achieved. It is extremely important to develop an international ethanol fuel market to create confidence among suppliers and consumers. But the international trade of ethanol fuel still faces major difficulties, including

- trade barriers;
- it is relatively easy to set up a domestic ethanol industry;
- countries that have – or plan to have – ethanol fuel programs often aim at the domestic rather than the external market;
- ethanol programs are often farmers driven, which implies government subsidies and distorts the international market, although this is now changing

The most dynamic markets are the US, and Brazil. An increasing number of countries, as stated already, are also considering the introduction of ethanol fuel programs of different scales for blending with gasoline, e.g. Argentina, Colombia, China, India, Mexico and Thailand. Ethanol fuel is a growing market, as it has a considerable potential for substituting oil given the right conditions. Predictions vary enormously depending on when cellulose, the most abundant raw material, can be used to produce ethanol commercially. If cellulose-based ethanol becomes a commercial reality, it will have major repercussions for the transport sector.

The environmental benefits alone could be enormous, since about 2.3 tons of CO_2 are saved for each ton of ethanol fuel, excluding other emissions such as SO_2. The market for ethanol is not confined to transportation but has many other applications such as cogeneration, domestic appliances, chemical feedstock, etc.

Table 5.1.5. Main producers and consumers of ethanol fuel (or bioethanol), 2002.

Country	Production of ethanol fuel [10^9 l]
Brazil	11.5 - 12.0
USA	7.6
EU	1.0
Others	0.5

[6]) A major concern in Japan is the monopolistic nature of the ethanol fuel market, e.g. only very few countries such as Brazil are able to export ethanol on a significant scale. And even countries such as Brazil have a very limited capacity to export. As things stand, demand could easily surpass supply by a wide margin which could cause serious market distortions.

Table 5.1.6. Sugar and ethanol production in Brazil 2001/02 and estimates for 2002/03 [02Ros2].

Year	2001/02	2002/03 (estimated)
Cane [10^9 kg]	243.4	286.3
Sugar [10^9 kg]	15.9	20.1
Ethanol [10^{12} m^3]	10.1	11.3-12.0
- Anhydrous	5.7	6.5
- Hydrated	4.4	4.8

5.1.6.1.1 Brazil

Brazil's ProAlcool program, the world's largest, was set up in 1975 and is estimated at nearly 12 Bl in the year 2002 production (see Table 5.1.6). The ethanol market will continue to grow steadily, particularly for blends. For example, the total car fleet is expected to grow from 14 million units in 2000 to over 29 million by 2015. At its peak (late 1980s), almost five million automobiles ran on pure ethanol (E100) and a further nine million ran on a 20 to 22% blend of alcohol and gasoline. From late in the 1980s the combination of high demand for ethanol, higher prices for sugar, an uncertain government policy, lack of investment, financial problems, climatic factors, etc. resulted in a shortage of ethanol. As a result, the fraction of new neat ethanol cars dropped to 51% in 1989 and to almost zero in 1997 [98Ros]. In 1999, the government ended all subsidies to ethanol fuel and since then it competes directly with gasoline in the free market. Demand for ethanol fuel has sharply increased largely due to the success of "flex-fuel" vehicles.

5.1.6.1.2 USA

The USA is currently the fastest growing market. Production fluctuates considerably, but in 2002 a record in production of 2.0 Bgal is expected. There is a good infrastructure with 66 ethanol plants and an installed capacity at the end of 2002 of 2.7 Bgal [02RFA]. The main producers are the states of Illinois, Nebraska, Iowa and Minnesota. Currently every vehicle marketed in the USA is approved for the use of up to 10% ethanol blended fuels, according to the RFA. Ethanol is sold in all States as octane enhancer or oxygenate blended with gasoline and currently represents 2% of the US gasoline fuel market. The more successful mix in the USA are the Flexible Fuel Vehicles (FFV) which can operate on 85% (E85) ethanol- gasoline or any combination of both fuels in the same tank. The Ethanol FFVs incorporate a modern microprocessor that continuously adjusts the engine operation and fuel air ratio, making it possible to operate on any combination of the two fuels.

The replacement of MTBE with ethanol would increase the demand for ethanol fuel by a further 3.2 Bgal. California is potentially the fastest growing market with a potential for 3 billion l/a [02RFA]. Although corn still remains the main source of ethanol, today 27 different feedstocks are also being used to produce ethanol.

The rapid growth of ethanol fuel has been part of a wider trend in support of cleaner environment and energy security policy objectives. Specific factors in favor of ethanol fuel in the USA include

- government intervention through legislation and tax incentives;
- low gasoline octane ratings caused by reduced use of lead after the approval of the Clean Air Act in 1977;
- concerns with US dependence on foreign oil supplies;
- environmental concerns, e.g. environmental advantages shown by ethanol fuel;
- US policy aimed at securing growers' income (i.e. through the protection it gives to corn-based sweeteners) while guaranteeing safe supplies for US consumers;
- tax concessions and operated loan programs: Since January 1991, the tax exemption has been set at 5.4 cents per gallon for a minimum 10% ethanol blend.

Of particular interests are the Alternative Motor Fuels Act of 1988 (AMFA), the Energy Policy Act of 1992 (EPACT), Clean Cities Program (CCP), the Clean Air Act Amendments (CAAA) and the establishment of a national Renewable Fuels Standard (RFS). The RFS is currently in the process of being established under the Energy Policy Act of 2002; it will require the use of an increasing amount of RE-based fuels to be blended with conventional motor fuels, staring at 2 Bgal in 2003, increasing to 5 Bgal in 2012 and remaining more or less constant thereafter. However, a debate is currently taking place on a comprehensive fuels agreement, partly motivated by the need to phase out MTBE. The new fuel agreement should provide a uniform, federal phase down of MTBE, eliminate the oxygenate standard, protect clean air gains and establish a national RFS (see www.ethanolrfa.org). On September 26th, 2002 the House of Representatives voted to submit a revised fuels agreement to the Senate. The proposal includes various changes to the previously passed agreement by the Senate, including

- removal of federal ban of MTBE;
- a delay of implementation of the RFS by one year until 2005;
- a delay of the full implementation of the 5 Bgal RFS by two years until 2014.

5.1.6.1.3 EU

After many years of disagreement, the EU has finally proposed a new legislation to promote alternative fuels [01EUC, p. 547]. This includes an Action Plan and two proposals for directives. The driving force for the support of biofuels in the EU was the Commission's Green Paper [00EUC] which introduced the objective to substitute 20% alternative fuels in the road transport sector by the year 2020, see Table 5.1.7. The EU plans to make blending biofuels and gasoline (ethanol and diesel) mandatory at a later day, as yet unspecified.

In 2000, the estimated contribution of biofuels was just 0.3% (0.8 Mt, approximately 1 Bl). The EU-wide gross oil consumption in 1999 was 593 Mtoe. Based on this, a 5% ethanol contribution will require circa 30 Mtoe (i.e. 37+Bl/a). The European Commission has identified three main potential alternatives that could be developed:

1) Biofuels (mostly biodiesel and ethanol);
2) Natural gas (medium term);
3) Hydrogen/fuel cells.

These alternative fuels appear to have a high volume potential (5+% each) of the total transport fuel consumption over the next 20 years.

Various countries are experimenting with *ethanol-diesel blends* in various proportions. For example, Australia with 15% hydrated ethanol-diesel, Sweden has a fleet of buses using ethanol-diesel blends, Germany with 15% ethanol & methanol, Chile with 12.5% methanol blends; Thailand with 15% hydrated ethanol in tractors and lorries. Brazil also has a large program of ethanol-diesel blends (2-10%) with encouraging results so far.

5.1.6.1.4 Technology trends

As indicated already, no major ethanol fuel programs are expected in the short term, but rather the introduction of smaller ones aimed at different levels of blending with gasoline and even with diesel be it in a smaller scale. The greatest potential breakthrough is ethanol from cellulose-containing materials, e.g. wood, bagasse, corn stover, etc. For example, the US market for cellulose-based ethanol has been estimated 1.8 Bgal for ethanol-gasoline blends up to 2007 and more than 10 Bgal after 2010 without any subsidy. The potential for neat ethanol in the long term is more than 120 Bgal, plus a similar amount for ethanol for the fuel cells [99NRC]. The use of ethanol in fuel cells, particularly ethanol-based hydrogen fuel cells, is currently of considerable interest because ethanol can overcome both the storage and infrastructure challenge posed by hydrogen fuel.

Table 5.1.7. Proposed minimum level of biofuels in the EU 2005-2010 [00EUC, p. 769].

Year	Percentage
2005	2.00
2006	2.75
2007	3.50
2008	4.25
2009	5.00
2010	5.75
2020 [1])	20

[1]) Estimated combined maximum percentage of all biofuels that can replace fossil fuels in transport.

5.1.6.2 Biodiesel

Biodiesel can be used neat (100% or B100) or in various blends. It can be used in any diesel engine with little or no modification and does not require any new refueling infrastructure. Biodiesel maintains the same payload capacity and range as conventional diesel and provides similar horse power (HP), torque and fuel economy. However, biodiesel has a greater octane number increasing the engine's performance and has better lubricant quality enhancing engine life. At the same time biodiesel produces far lower emissions, (see www.epa.gov; www.afdc.doe.gov/afv/biodiesel.html). Biodiesel, particularly B100, can have cold start problems, so fuel tank and filter heaters may be needed in cold climate, and some other biodiesel compatible elastomers (hoses, gaskets, etc) are also required.

The Austrian Biofuels Institute (ABI) carried out a detailed study for the IEA to determine worldwide production and potential of biodiesel. The study covered 28 countries around the world in which biodiesel activities were reported since 1982 [97ABI]. In total, 85 biodiesel production plants were identified of which 40 were in the range of 500-3000 tons and the rest in a capacity range of 5000 to 120000 tons. By region, the numbers of biodiesel plants, regardless of capacity size, were

- 44 plants in Western Europe (about 450000 tons), Italy being the leading country with 11 plants;
- 29 plants in Eastern Europe, Czech Republic (22000 tons) being the leading country there with 16 biodiesel plants;
- 8 plants in North America;
- 4 in the rest of the world.

The overall capacity continuously grew from 0.111 Mt in 1991 to 1.3 Mt in 1997. The estimated worldwide capacity in 2002 was about 2.5 Mt [01Koe]. Western Europe represents by far the largest volume potential, but the strongest increase of capacity development has been in the USA [97ABI]. Other countries with large-sale potential for biodiesel are Brazil and Malaysia.

5.1.6.2.1 Feedstock

The ABI study identified rapeseed as the most important source of biodiesel with a share of over 80%, followed by sunflower oil with over 10%, mostly used in Italy and Southern France. Soybean oil is preferred in the USA. Other raw materials are palm oil in Malaysia, linseed oil and olive oil in Spain, cotton seed oil in Greece, beef tallow in Ireland, lard and used frying oil (UFO) in Austria and other waste oils and fats in the USA. A new diesel is also being made from coal and natural gas with the Fischer-Tropsch process, and in the future it may be possible to obtain it from biomass (see www.ott.doe.gov/biofuels/). Considerable advances have been made in biodiesel production and use including

- diversification of feedstock, although rapeseed, soybean oil and palm oil still dominate;
- process technology, fuel standards ensuring higher fuel quality;

- better marketing;
- diesel engine warranties;
- legislative measures, particularly in the EU and USA.

5.1.6.2.2 Biodiesel in the EU

The EU leads the world in the production and use of biodiesel with an installed capacity of 2.24 Mt[7] in over 40 production sites in 2004, representing approx. 1.5% of the diesel market. With 3.18 Mt, the 2005 production was increased by 65% compared to 2004, and a further continuous increase in the next decade can be expected. The most important biodiesel producers in the EU are Germany (1.04 Mt), France (0.35Mt) and Italy (0.32 Mt). Many plants are still in an experimental stage, often with support from local authorities, e.g. most tests are carried out in public transport systems (see www.ebb-eu.org/stats).

5.1.6.2.3 Biodiesel in the USA

Biodiesel production in the USA has increased rapidly in the past decade, particularly after the Amendments of the Energy Policy Act of 1998, encouraged by government support, pressure from soy bean producers and by the potential large market. The American Biofuels Association (ABA) considers that, with government incentives comparable to those provided for ethanol, biodiesel consumption could reach 2 Bgal or about 8% of highway diesel consumption mostly in blends of about 20%, primarily bus fleets, heavy-duty trucks, agricultural vehicles, electric generators, etc. The current production is estimated to be about 150000 tons, or 1.7 Bl.

5.1.6.3 Biogas production and utilization

Biogas production and use can be grouped into three main categories:

1) Small domestic production/applications;
2) Small cottage industrial applications;
3) Industrial production/uses.

A significant change in biogas technology, particularly in the case of larger industrial plants, has been a shift away from energy alone towards more environmentally acceptable technology which allows the combination of waste disposal with energy and fertilizer production in both developed and developing countries. This has been helped by financial incentives, advances in energy efficiency, dissemination of the technology and the training of personnel.

Biogas is also increasingly being used to generate electricity. Although there are some technical problems (i.e. traces of many compounds such as hydrogen sulphate and halogenated hydrocarbons), there are good prospects. It is technically feasible to upgrade biogas to about the same quality as natural gas by removing carbon dioxide in the biogas, and the methane level increases from the usual 40-60% to about 95%. This approach leads to a potential competitiveness with natural gas.

Biogas is produced in many countries around the world, but only a few, namely China, India, Nepal and Denmark have a countrywide program. It seems that the traditional small-scale family biogas plants are changing toward industrially and community-based plants. The future production of biogas seems to be very much linked to industrial plants using both Municipal Solid Waste (MSW) and animal manure from large farms although in some rural areas community biogas plants may also be feasible.

Biogas has also been used as a transport fuel for decades, mainly in captive markets, e.g. vehicle (buses, refuse vehicles, etc) mostly in urban centers. This is largely due to advances in gas-powered vehicles which have greatly benefited from the use of biogas in transport applications. The major disadvan-

[7]) 1 ton of biodiesel equals 1136 liters.

tage of biogas as a transport fuel is its low calorific value, which limits the vehicle range. As a main advantage, it can be integrated within the infrastructure and energy applications designed for natural gas. There are many demonstration schemes around the world for the use of biogas in transport applications. However, it is unlikely that biogas will have a major impact in the transportation system; much will depend on the development of natural gas stations and how well biogas can be integrated[8].

5.1.6.3.1 China

China has a long historical experience with biogas, but data is fragmented and thus it is difficult to provide a good and reliable estimate. Currently it is estimated that there are over 6 million household-based biogas digesters and about 500 industrial units in operation which represent a small proportion (less than 10%) of the potential organic waste from agriculture and industry. The many failures of biogas in China are due to a complex combination of technical, political and financial issues. New industrial projects are being built in order to overcome this legacy [00Jun]. It is estimated that there are about 190 biogas-based power electricity generation units with an annual generation capacity of 3 GWh.

5.1.6.3.2 India

There were 3.3 million biogas plants in India in 2001, while the total potential is estimated to be about 12 million units [02MNE]. As in China, the traditional family-based biogas plant is declining in favor of community biogas plants. Biogas plants require a relatively high initial investment and are not always suitable for the household needs. The National Program on Biogas Development (NPBD) includes the following goals:

- Provide clean cooking energy;
- Produce enriched manure to supplement chemical fertilizers;
- Improve the quality of life for rural women;
- Improve sanitation and hygiene.

5.1.6.3.3 Nepal

Nepal is another country that has tried hard to develop a biogas industry. Up to 1998 about 49000 biogas plants were built of which 37000 were built under the Biogas Support Program from 1992 to 1998, producing 20 million m^3 of biogas and serving over 200000 people. An additional 80000 units are planned to be installed in the next few years. This program has provided multiples benefits on household, local and national levels including

- an average cooking time saving of three hours daily per household,
- improved indoor air quality,
- release pressure on deforestation and soil depletion,
- annual displacement of about 100000 tons of firewood,
- $1.27{\cdot}10^6$ liters of kerosene and
- 157000 tons of CO_2 [00Van].

[8]) This does not include biogas produced by the Fischer-Tropsch process (or gasification).

5.1.6.3.4 Denmark

Denmark had 20 large centralized plants with a capacity ranging from 25 to 500 t/day and produce between 1000 and 15000 m^3/day of biogas. Waste disposal is a major aim of the biogas production. Currently, most biogas plants have an acceptable economic situation, but perhaps the same cannot be said with regard to the older plants. According to the DIAFE, the *"Danish centralized biogas concept offers a total and appropriate system for treatment, sanitation, redistribution and nutrient utilization from livestock slurry and organic waste"* [99DIA].

Biogas plants are becoming an increasingly popular option for waste management where several sources such as animal manure, crop residues, industrial wastes, and sewage are combined in a single digestion plant. There are four main products:

- Biogas;
- Environmental protection;
- Production of fertilizers;
- Soil improver or compost material.

In summary, the main driving force in biogas production is not energy but the necessity of addressing environmental and sanitary problems. Biogas, rather than an alternative energy source, could well be considered a potential solution to environmental problems posed by excess manure handling, water pollution, etc. Thus, it is highly unlikely that biogas will ever play any significant role in transportation. Instead, its use would be limited to niche markets such as buses and refuse vehicles, mostly in urban centers. However, the market for electricity appears more promising.

5.1.6.4 Charcoal

Charcoal in produced in large quantities, but it is extremely difficult to estimate the global charcoal production since in most cases it is an integral part of the informal economy of many developing countries, characterized by small scale operations involving a very large number of small farmers and poor rural people. Estimates vary from 26 to over 100 million tons (104 to 400 m^3) of charcoal produced annually worldwide. Contrary to the general view, charcoal consumption has increased in recent years and is becoming an important source of energy as people from rural and urban areas of developing countries shift from wood to charcoal use [96Ros], [02Ros2]. For example, the IEA foresees an almost threefold increase in charcoal production and use from 22.3 Mtoe (approx. 90 million m^3) in 1995 to 58.3 Mtoe (approx. 235 million m^3) in 2020 [98IEA], which may be in fact a highly conservative figure.

In most developing countries charcoal is mainly used as a domestic fuel for cooking and heating and also in the cottage industries. However, it is also an important industrial, reduction and thermal agent in various industries. It is used in numerous metallurgical industries (especially pig iron, foundries and forges), cement factories and for chemical applications, as is the case of Brazil, the world's largest producer and consumer of industrial charcoal (about 6.75 Mtoe were produced in 2000), used almost entirely in steel making, cement, metallurgy, etc. In 2002, over 72% of charcoal will be produced from eucalyptus plantations compared to 34% in 1990 [02ABR].

Various points need to be emphasized:

- The enormous socio-economic importance of charcoal production and use in developing countries. Hundred of thousands, even millions, of people totally or partially depend on this activity.
- Low energy efficiency (e.g. 12% in Zambia, 11-19% in Tanzania, 9-12% in Kenya) which results in considerable waste of resources. Brazil is among the world most efficient charcoal producers with an efficiency ranging between 30-35%. Plantation yields are about 20 m^3/ha/a and costs are between 0.4 and 0.5 RS$/GJ[9] [02ABR].

[9]) 1 $US = 3 $RS.

- Contrary to general belief, charcoal production is not the main cause of deforestation in the majority of the cases. Experience from many countries shows that charcoal-making often promotes tree planting and also results in greater trade, wasteland development, income and employment generation [93FAO][10]. Charcoal is largely produced from forestry residues resulting from the expansion of agriculture, pasture land, waste from wood processing, saw mills, forestry's thinning and, more professionally, from biomass plantations. But in many areas of Africa in particular, charcoal making also leads to deforestation.
- As living standards increase, many people in urban and peri-urban areas shift to charcoal, together with many cottage industries. Urban energy demand in many African countries is almost exclusively in the form of charcoal. Locally, the production and trade of charcoal creates income for low-income groups in rural and urban areas [01SEI]. In addition, charcoal does not produce any serious health effects compared to wood fuel.

5.1.7 Socio-economics of modern biomass

Biomass energy is intrinsically intertwined with land use and labor, and there is an intimate interaction with local socio-economic development and the environment. For these reasons biomass energy programs need to be specially scrutinized to ensure that varying needs are met, for example

- satisfying/improving basic needs,
- provide income opportunities,
- make good and effective use of land resources,
- promotion of health needs and environmental protection.

From this point of view, biomass energy schemes are rather complex if all these variables are to be met. But is it realistic to expect so much from biomass energy schemes? Why should biomass energy be different from say, food production?

5.1.7.1 Biomass energy and rural development

The role of agriculture in energy production is lost in history. From early hunter-gathering to actual agriculture, plant products provided human food, fuel, fodder, building material, etc. The diverse use of biomass utilization is well represented in the so-called *six Fs* *F*ood, *F*uel, *F*eed, *F*eedstock, *F*iber and *F*ertilizer. Biomass was the main source of energy up to the early 20th century and remains so in many rural areas of developing countries. This role has been largely unrecognized in many parts of the world by politicians and energy planners alike.

Thus, what would the implications of an enhanced role of bioenergy be in the future for rural development, if current energy scenario projections were correct? The availability of modern biomass energy carriers could have significant implications in modernizing agricultural practices in many developing nations (e.g. a sustainable increase in food production, economic growth and social development). Already the modernization of bioenergy such as the cogeneration of electricity from sugarcane bagasse in Brazil and India or improved stoves and biogas in China and Kenya is producing very positive effects.

Living conditions in rural areas, as anywhere else, are greatly affected by the amount and quality of available energy, which is currently a major limitation in many developing countries. Modernization of biomass energy is not that simple if it is aimed at reducing poverty. It requires a multi-pronged and multi-sector approach. One concern often raised is that by modernizing biomass resources, poor people can be negatively affected as the resources are currently available for free in most cases (which is a fallacy since women and children spend considerable time gathering fuelwood which could be spent in other economic

[10]) This is not always the case as the most damaging activities come from illegal charcoal-makers.

activities). However, it would be unrealistic to think that, for example, woodfuels will continue to be available for free as it has often been the case so far.

Increased energy use can only be beneficial if it provides essential services such as cooking, lighting, heating, water pumping, transport, industrial uses, etc. Adequate food supplies and reasonable quality of life require energy both in commercial and non-commercial forms; in developing countries the latter is the most important, particularly in rural areas. Considering that about 2.5 billion people live in rural areas, this is a problem that cannot be ignored. However, it is important to bear in mind that bioenergy is just one alternative since there are other RE alternatives, such as wind and PV power, which have also a considerable potential. The best strategy to provide energy to rural areas may be an integrated approach by combining biomass energy with other RE such as wind and PV and even fossil fuels.

Bioenergy could play a significant innovative role in a flexible and sustainable system where the supply of food, energy, feed, etc. is integrated. For example, there are over 3.4 million households in China using integrated technology to produce biogas, digested sludge, fertilizer and effluent utilization. A "bioenergy village" concept has been proposed in the past, based in the idea that bioenergy (in its modern forms) should be available to provide all the essential needs of the village. It must be highly integrated to minimize waste and to allow the application of the best techniques, practices and locally available skills. The "bioenergy village" concept can certainly not be the panacea to solve the food-energy problem, but it may be able to make some contribution, particularly if combined with other RE. Modern and advanced processing of food, energy and feed together with marketing and distribution systems need to be adopted to preserve the whole dynamic structure. Maximizing economic growth is not the best way for social development if it does not trickle down to the neediest people [99Ros].

The economy of many developing countries relies on agriculture where most of the work is often done using primitive tools and working practices that have seen little change for decades. Food can be produced in primitive ways with very little or no fossil fuel energy (i.e. using slash-and-burn agriculture). For example, FAO statistics show that human effort provides over 70% of the energy required for crop production in many poor countries. However, population growth and environmental, economic and social pressures make this option unrealistic for the future. These agricultural practices, as with traditional bioenergy, also need to be modernized and this is where RE has an important role to play. Also, it would be wrong, as some bioenergy enthusiasts argue, to expect bioenergy to solve the social and economic problems of the needy. The most it can do is to help in the process of socio-economic development.

5.1.7.2 Bioenergy and employment

Employment opportunities have long been recognized as being a major advantage of biomass energy because of the many multiplying effects which help to create more jobs and thus greater economic activity, strengthening the local economy. However, this is a complex issue since it is important to take into account the net job creation (which can be very small, particularly if modern applications are considered[11], job quality, job intensity, etc. Nonetheless, bioenergy has been shown to be a significant source of employment and income generation for many poor people in developing countries (and increasingly in industrial countries), particularly for the land- and jobless who would have few or no means of livelihood otherwise. Evidence seems to indicate that bioenergy is very often closely and intricately interwoven with local economic and employment conditions and hence with local, regional and even national prosperity.

Among bioenergy related activities, agriculture and forestry are the largest and most intensive sources of employment. A rough estimate of employment suggests that annually about 60 million men are employed in the forestry sector globally – 48 million in developing countries and 12 million in industrial countries. Some 20-25 million men/year are calculated to depend just on fuelwood collection and charcoal production in developing countries [96FAO1]. For example, in the Philippines in the early 1990s an estimated 830000 households (530000 gatherers, 158000 charcoal makers and sellers, 40000 rural traders and 100000 urban traders) were involved in the woodfuel trade from gathering to retailing, covering 10%

[11]) In modern applications (conversion plants), employment generation seems to follow conventional economics, that is technology replaces employment.

of all rural households and about 40% of their cash income [96FAO2]. In 2001, Brazil's sugarcane ethanol-based industry directly employed 610000 people and 980000 indirectly [02Wal].

Another important factor is the cost of employment creation which is quite cheap in comparison to other industrial activities. In Brazil, for example, the creation of a job in the sugarcane-ethanol industry in the mid 1990s required an investment of about 11000 $, compared to 220000 $ in the oil sector, 91000 $ in the automobile industry and 419400 $ in the metallurgical industry [00Ros2]. Much of this bioenergy-related work represents a secondary activity for farmers. Table 5.1.8 shows the estimated direct employment generation for both fossil fuels and RE. The most labor intensive are photovoltaics with 76000 jobs/person/a, followed by ethanol from sugarcane with 4000 jobs/person/a. The World Bank conducted a study that also confirms the central role of bioenergy in generating net employment when compared with fossil fuels [99WEN].

Table 5.1.9 summarizes net employment and impacts on climate policy of various studies in the energy-related sectors. An EU study indicates that the energy from RE will more than double by 2020 and could create over 0.9 million jobs (385000 full time equivalent and 515000 in biomass-related activities) [00Bro]. However, the estimation of the employment impacts of bioenergy is a complex issue because there are many uncertainties involved. There are two major issues that need to be studied in greater detail:

1) *Effect of intensity of employment*
   Does for example such labor intensive activity hamper the economic development? Obviously it has major implications, and more studies are needed to establish this relationship more clearly.
2) *Quality of employment*
   Most of the jobs generated by traditional bioenergy (as is the case with many other agricultural and rural activities) are unskilled and of poor quality, although the same cannot be said of modern bioenergy applications which involves mostly highly qualified and well paid jobs.

Table 5.1.8. Direct jobs in energy production [02Gol].

Sector	Employment generation [jobs/TWh]
Petroleum	260
Offshore oil	265
Natural gas	250
Coal	370
Nuclear	75
Wood energy	1000
Hydro	250
Minihydro	120
Wind	918
Photovoltaics	76000
Ethanol (from sugarcane)	4000

Table 5.1.9. Job impact findings, selected studies on climate policy [00Ren].

Country	Policy change	Years	Carbon reduction [10^6 t]	Net employment gain
Austria	- cogeneration, energy efficiency, RE, alternative transportation	1997-2005	70	12200+
	- biomass, higher taxes of fossil fuels	1997-2005	20	30000+
Denmark	greater natural use, district heating, cogeneration, energy efficiency, RE, total energy consumption stable	1996-2015	82	16000+
Germany	greater efficiency, phasing out nuclear, less oil and cost use, 10% of RE, alternative transportation policies	1990-2020	518	208000+
Netherlands	efficiency gains in transport, industry, electric equipment, buildings, greater use of wind power	1995-2005	440	71000+
United Kingdom	greater use of cogeneration, efficiency, RE	1990-2010	206	537000+
European Union	installation of high performance double-pane windows in 60% of dwellings	10 year period	940	126000+
USA	improved efficiency in transportation, industry, power generation, buildings	1990-2010	188	870000+

5.1.7.3 The “Food versus fuel” argument

This has always been a controversial topic because of the many misconceptions surrounding land availability, particularly at a time of rapid population growth. To better understand this issue it is necessary to understand the intertwined nature of food and energy production and the complex factors involved ranging from political, socio-economic and cultural factors, mismanagement and so forth. This can become a hot issue again if large economic incentives are given to biomass energy, particularly to plantations, under the Kyoto Protocol. Dedicated energy forestry/crops have been heralded repeatedly in most energy scenarios as a potential major source of energy in the 21st century, as discussed above.

It is understandable that there should be a great deal of concern when land is suggested to be converted to energy purposes while there are so many undernourished people around the world. But the relationship between energy and food production needs to be understood. Food production is a complex socio-economic, political, and cultural issue that goes beyond the earth’s carrying capacity to produce food. If farmers are given the opportunity, (i.e. capital, economic incentives, land tenure rights, abundant energy supply, etc.) they will be able to produce more food than it has been the case so far. For example, India increased its food grain production from 50 to 200 Mt, while the population has increased only threefold from 330 million to over one billion. But for this to happen, the right conditions must be put in place which is highly unlikely. Therefore it is important that all these complex issues are recognized as a part of the problem’s solution, ranging from high consumption of grain as animal feed, mismanagement of resources, the role of staple food in developing countries, etc. A particularly important aspect is the role of women who are responsible for 60-80% of the staple food production in many developing countries and who have often been ignored or undervalued, and as a result they did not receive the recognition they deserve so that their inputs were not targeted by yield-enhancing techniques.

To feed a growing population satisfactorily we need more than increased agricultural production, it is about political changes that prioritize agricultural R&D, about changing people’s attitudes, about improving the quality of life of many and about providing incentives and motivation. It is also a precondition to have abundant and accessible sources of energy if this is to be achieved. And this is where bioenergy and other RE could play a role. These represent major changes, but they are possible. For example, the break up of the Soviet Bloc in 1989 plunged Cuba into the worst economic crisis of its history. Its agriculture was highly dependent on imported pesticides, fertilizers and farming equipment, and without these inputs, domestic production led to an estimated 30% reduction in calorie intake in the early 1990s. Cuba was faced with a dual challenge of doubling food production with half the previous inputs, but responded to the crisis with a national call to increase food production by restructuring their agriculture. This transformation was based on a conversion from a conventional, large scale, high input, mono-crop agricultural system to a smaller scale, organic and semi-organic farming system. It focused on utilizing local low cost and environmentally safe inputs and relocating production closer to consumers in order to cut down transportation costs. By 1998, an estimated 541000 tons of food were produced in Havana alone for local consumption and some neighborhoods were producing as much as 30% of their own subsistence needs [98Mur]. Cuba is not the only case. Urban agriculture has a role to play in many parts of the world. For example, it is estimated that 800 million people worldwide harvest 15% of the world's food supply by growing vegetables and livestock in cities such as Hong Kong, one of the most densely populated cities in the world which produces two-thirds of its poultry and almost 50% of its vegetables [99Ros].

5.1.7.4 The role of externalities

The external costs of energy have largely been ignored until quite recently, partly because the vested interests of the conventional energy lobby, but also because environmental and social costs are very difficult to estimate due to the difficulties involved in assigning a fixed value to human life and environmental amenity. It is a complex issue that can only be mentioned in passing. However, it seems clear from a large number of studies, e.g. [00Gro], that the external cost of fossil fuel energy can be substantial and will make RE more competitive if internalized.

One of the major problems is to identify many of the hidden subsidies that fossil fuels receive directly or indirectly in a multitude of forms. Take, for example, the USA where a report by the General Accounting Office [00GAO] shows that the petroleum industry has received over \$150 billion in tax breaks in the past 32 years alone, excluding foreign investment tax credits estimated to cost de Treasury a further \$7 billion per year. This compares with about \$12 billion paid to the ethanol industry since 1979. The ethanol tax credit in the USA is currently 0.54 \$/gal and applies to ethanol and the ethanol portion of the gasoline additive ethyl tertiary-butyl ether. These tax credits have been extended until the year 2007, but with the following reductions: 0.01 \$ in 2001-02; 0.02 \$ in 2003-04 and 0.03 \$ in 2005-07 [00GAO], [99NRC]. Some states also provide additional subsidies such as North Dakota providing a 0.40 \$/gal.

Ethanol is just one of the several products made from corn in a wet milling operation. Other products include food and industrial starches, dextrose, high fructose and milling co-products such as corn gluten feed, corn oil, etc. Thus, when estimating ethanol fuel costs, it is also necessary to allocate costs to various portions of the raw material. In fact a new concept is beginning to emerge, the so-called "bio-refineries" where ethanol is just another product. Therefore the challenge would be to focus on a new multiple products concept, e.g. food, energy (liquid, gas, heat and electricity), high value-added chemicals, feed, fiber, etc. There is no particular reason why "bio-refineries" can not be comparable with a modern petroleum refinery.

The external cost debate has intensified with the liberalization of the energy market because such forces are powerful and contradictory with regard to the environment and sustainability of energy. Broadly speaking, there are two currents of thought:

1) Those who believe that a market liberalization threatens the political and economic basis of RE, mainly because
   - as market liberalize, governments' ability to influence energy markets diminish,
   - strong governmental support for RE would not solve the problem because protectionism will never lead to maturity;
2) Others argue that a market-based approach to energy will make RE more competitive, provided there is a fair "playing field", e.g. that all external of costs of energy are internalized, the polluter pays and no hidden subsidies are given to the traditional energy sources.

Table 5.1.10. Tax incentives for petroleum and ethanol fuels, estimates of revenue losses over time (see [00GAO] for further details of calculations).

Tax incentive	Summed over years	Revenue losses [10^9 \$], adjusted to 2000
Petroleum industry		
Excess of percentage over cost depletion	1968-2000	81.68 - 82.00
Expenses on exploration & development costs	1968-2000	42.85 - 54.58
Alternative (non-conventional) fuel production credit	1980-2000	8.41 - 10.54
Oil & gas exception from passive loss limitation	1988-2000	1.06
Credit for enhanced oil recovery costs	1994-2000	0.48 - 1.00
Expenses of tertiary injectants	1980-2000	0.33
Ethanol industry		
Partial exception from excise tax for ethanol fuels	1979-2000	7.53 - 11.83
Income tax credits for ethanol fuels	1980-2000	0.19 - 0.47

5.1.8 Environmental considerations

The IPCC indicates that the CO_2 concentration could rise to a potentially devastating 540-970 ppm by 2100, up from a level of 367 ppm in 2000. RE have a large part to play in CO_2 mitigation. It is estimated that under the business-as-usual scenario, the global annual CO_2 emissions from power stations alone would be 4000 MtC by 2020 compared to 2400 MtC in 2000. If these plants were designed to displace 50% of CO_2 by using cleaner technologies and RE, about 1270 MtC could be displaced by 2020 [01Sim].

The use of traditional biomass has been associated with environmental degradation and health hazards. Recent evidence shows that 2/3 of all woodfuels originate from non-forest land and thus are not the cause of deforestation as was stated in the 1970s. As a FAO study puts it, "w*ood energy use is not and will not be a general or main cause of deforestation"* [97FAO]. Health hazards are often caused by underdevelopment and cultural practices rather than by the nature of the fuel itself. Thus, bioenergy is increasingly being associated with environmental sustainability and climate stabilization. Two areas are particularly promising:

1) Liquid biofuels for transportation;
2) Cogeneration of electricity from sugarcane bagasse.

Automobiles generate more air pollution than any other human activity, making a large contribution to GHG (notably CO_2), and are the fastest-growing energy consumption sector worldwide. Each year the transportation sector produces more than 2000 MtCe or over 30% of the world carbon emissions. Because of the rapid growth of the transportation sector, the predicted increase in the future will have major environmental implications. Among the alternatives, the use of alternative environmentally sustainable transportation fuels such as ethanol, methanol, biodiesel, etc. offer a good potential for reducing emissions, as experience from Brazil and the USA shows. In Brazil, the net carbon reduction potential from ethanol fuel is about 9.5 MtC/a. If the full cycle is considered, each liter of ethanol avoids the emissions equivalent of 8 liters of gasoline; and each liter of gasoline blended with 10-20% ethanol emits 0.066 to 0.132 kg less carbon than one liter of pure gasoline [04Mac]. The net contribution of sugarcane to CO_2 emissions amounts to 12.7 MtC/year. The CO_2 emissions avoided with the use of ethanol and bagasse correspond to nearly 18% of the total emissions from fossil fuels used in Brazil.

5.1.8.1 Carbon sequestration versus carbon sink

The considerable potential of biomass as a carbon sink and a substitute for fossil fuels has long been recognized, e.g. in the Kyoto Protocol, articles 3.3 and 3.4. The IPCC estimates that between 60 and 87 GtC could be stored in forests between 1990 and 2050, or between 12-15% of the forecast fossil fuel emissions. Various strategies have been put forward to tackle the GHG emissions:

- Sustainable production and use of energy resources that results in neutral CO_2 production;
- Sequestration of CO_2, which creates carbon sinks. Since it was first proposed in 1977 there have been numerous analyses of the potential for forests to mitigate the global CO_2-induced greenhouse effect by sequestering carbon in their standing biomass. Growing trees as a long-term carbon store will be important only where the creation of new forest reserves is deemed desirable for environmental, ecological or economic reasons and on low productivity land;
- Direct substitution of fossils fuels is advantageous and appropriate, with its greater environmental and ecological benefits.

Various studies have concluded that displacing fossil fuel with sustainably grown biomass converted into useful energy with modern conversion technologies would be more effective in decreasing atmospheric CO_2 than sequestering carbon in trees [00Hal]. The extent to which biomass energy would decrease CO_2 emissions depends on the ability of, say, wood to displace coal, which is the more probable short to medium term option compared to biomass-derived liquid fuels offsetting coal, gas and oil-derived fuels. The greater reactivity and lower sulphur content of wood compared to coal gives considerable advantages in advanced conversion technologies. Thus, if biomass is considered primarily as a substitute for coal using modern conversion technologies for producing either electricity or liquid synfuels, the effect on atmospheric CO_2 would be comparable to what could be achieved with carbon sequestration. To obtain maximum benefit, trees, other than in primary forests, should be used as an energy source (or long-lived product) at the end of their growing life. It is probably preferable in most circumstances (except mature and primary forests) to use the biomass on a continuous basis as a substitute for present and future fossil fuel use [00Hal].

5.1.9 Institutional changes in the energy market – Implications for bioenergy

In many industrialized countries, deregulation is turning energy into a commodity that is obtainable at any time, anywhere and for every need. Technological advances are changing the way we produce and store energy, control loads and transmit it. Energy is becoming an integral part of many other services, changing constantly, pushed by new technology, advances in information communication technology, etc. The growing competitiveness is intensifying the entrepreneurial challenge and search for new alternatives. However, in many of the poorer nations the most pressing problem is how to provide affordable energy or simply some kind of energy, particularly to the needier people. It is not yet clear how current changes in the energy market will affect these sectors of society. Nonetheless, decentralization and the trend towards local power generation should benefit RE and hence those in greater need.

High costs and inefficiency of traditional power utilities began to undermine their basic assumptions, and later in the 20th century, the monopolistic structure began to be challenged, leading to radical changes around the world. The four major forces behind this trend are:

1) Privatization (as a direct response to the perceived inefficiency of sate monopolies);
2) Decentralization;
3) Globalization;
4) Concerns about the environment.

Large central power stations are giving way to hybrid and decentralized power systems. This should allow the construction of new electric power plants near users, thus avoiding new costly transmission lines and transmission losses. In the USA, for example, it has been estimated that new transmission and distribution cost about 1260 $ per kilowatt of new capacity. The benefits of distributed generation are even greater if combined with CHP. Distributed generation built near high power quality users and connected in parallel with local grid can be almost 100% reliable to consumers [01Cas].

Energy supply is undergoing a shift from the mainly generation-oriented structure with its emphasis on a reliable provision of stand-by capacity to a consumer oriented, economically and environmentally optimized energy supply, at least in the most advanced countries. This will allow

- the incorporation of all suitable energy sources in decentralized energy supply concepts, which allows greater optimization and control at local levels;
- an increase of the economic benefits from the use of RE energy in the mixture;
- the use of the latest information and communication technology [02Bit].

In summary, broadly speaking, the major forces that will continue to shape the energy/electricity utility in the future, at least in the most industrialized countries are:

- *Governance*
  Many market-oriented systems are emerging, all of which require a greater individual participation through a greater choice of electricity supply. Increasingly market-oriented approaches are changing not only the electricity utilities but also many other industrial sectors.
- *Environment*
  Increasing global concern with the environment and sustainability will not go away, particularly in the power industry, since it is a major contributor to atmospheric pollution and waste disposal. The power utilities will undergo increasing environmental scrutiny. All indications are that the power industry will be forced to adopt the most environmentally friendly technologies available.
- *Technology*
  Technological changes are creating a rapid shift to decentralization. Large, centrally controlled power units are giving way to smaller and more flexible, modular units managed with information technology[12]. Modern technology is affecting all aspects of power generation, distribution and delivery [01Wei].

The future power utility system is shaping quickly which indicates that it must be able to provide energy services that are clean, affordable, secure, and tailored to meet the needs of the most environmentally minded customers. Sustainability, reliability, affordability, efficiency and environmentally clean technologies are concepts that will play an increasing role in the provision of future energy services. These changes will have different effects in industrial and developing nations. Various instruments and policies have been or are being tried to accommodate these emerging changes, ranging from tax incentives to institutional and capital support. For example, the EU is experimenting with various forms of financial incentives, although the member countries have followed up different approaches (i.e. a mixture of tax systems, grants, mandatory laws requiring purchase of renewable output, etc.). But the basic tenet is "government hands off" in favor of free market and cheap electricity. Often this has led to considerable confusion because nobody seems to know exactly what is going on.

None of the methods tried have been completely successful in assigning widely acceptable values so far, e.g. new methodology for incorporating the external costs. This is because it is extremely difficult to assign economic values to externalities that are acceptable to a wide audience. The different methods tried in the energy sector, particularly in the EU and USA, can be summarized into two main concepts:

1) Support to create the market and allow the capital to take its course;
2) Support to create the capital and then let the market forces take their course;

[12]) More recently there is growing interest to revitalize the nuclear industry. There are many reasons, but one that the nuclear lobby likes to emphasize is the environmental benefits, which is far from the truth. The main point is that the construction of many new nuclear power plants will have serious implications for energy decentralization.

Table 5.1.11 summarizes the main mechanisms used to support new technologies in the utility sector. This on-going effort is at various levels of government, in different markets and with different technologies. Common factors include

- high initial capital costs,
- immature financial support mechanisms,
- lack of market infrastructure,
- market fragmentation and confusion,
- increasing competition and falling electricity prices,
- institutional barriers, enacted mostly by incumbent utilities,
- uncertain regulatory framework at almost all levels.

Conventional energy suppliers are diversifying into conglomerates with a multi-commodity approach. Each company is invading each other's territory and poaching each other's customers. Trading and marketing are now major factors. These changes are being further accelerated by the power of internet-trading which is opening up many new business opportunities, with many new traders appearing who are at the same time forcing the market to open up even more. It is not clear yet how the technological, management and market changes will affect the different energy market around the world, how the effective technology transfer in these areas will be in the poorer countries and to what extent RE can help to solve these problems. However, decentralization should favor the introduction of RE because energy can be generated and consumed locally. In the case of liquid biofuels the situation is more complex because conventional fuel (oil) still monopolizes the market and no clear alternatives can yet be envisaged, although ethanol and biodiesel could substitute 10-20% by 2020 based on current trends.

Table 5.1.11. Summary of the main concepts in support of new technologies [01Wei].

Capital support to create the market	Support to create the capital
- Renewable Portfolio Standard (RPS)	- Non Fossil Fuel Obligation (NFFO)
- Standard Offer Contracts (SOC)	- Cost buy downs (CBD)
- Electricity Feed Laws (EFL)	- Production Credits (PC)
- Efficiency Standard (ES)	- Tax Policies (TP)
- Tag/Green Market Certificates (TAG/GMC)	- Climate Change Levies (CCL)
- Wind Development Concessions (WDC)	- Energy Efficient Mortgages (EEM)
- Fuel Price Risk Avoidance Standards (FPRAS)	- System Benefit Charges (SBC)

5.1.10 Conclusions

Global changes in the energy market, particularly decentralization and privatization, offer RE new opportunities and challenges. Experiments in market based support are changing the way we look at RE, leading to a growing interest in local energy solutions. Thus, is RE – and more specifically biomass energy – finally reaching maturity? Globally there is a growing confidence that RE in general is maturing rapidly in many areas of the world and not just in niche markets. It is important to recognize that the development of biomass energy will largely be dependent on the development of RE as a whole, as it is driven by similar energy, environmental, political, social and technological considerations, although bioenergy is a more complex issue.

The REW conducted perhaps the most comprehensive international survey of the RE industry, with over 12000 questionnaires distributed in 164 countries. Responses from 93 countries have revealed an almost universal optimism, ranging from 60 to 75% about the expectations of growth of RE in the near future [01Mah].

The 1970s were pioneering years providing a wealth of innovative ideas on RE which were further advanced in the 1980s, when the computer revolution played a key enabling role. In the 1990s, improvements in RE allowed the technology to meet emerging market opportunities, e.g. gasification, cogeneration/CHP, etc. This opportunity was very much linked to the growing concern with climate change and the environment. The early part of the 21st Century may be dominated by a global policy drive to mitigate climate change. It is essential that biomass energy is integrated with existing energy sources and be able to meet the challenges of integration with other RE and fossil fuels.

Bioenergy in its traditional forms is still the main source of energy in many developing countries and will continue to be so in the foreseeable future. But modern applications are increasing rapidly either as complementary fuel or in modern applications. Bioenergy has often been associated with poor environment and health hazards, but these attributes are not inherent to bioenergy but a consequence of underdevelopment (i.e. poor housing conditions with no ventilation), cultural factors etc. Recent evidence shows that use of biomass fuels does not necessarily cause environmental degradation or health hazards.

For bioenergy to have a long term prospect, it must be produced and used sustainably and clearly demonstrate its environmental and social benefits in comparison to fossil fuels. The development of modern biomass energy systems is still at a relatively early stage with most of the little R&D allocated focusing on the development of fuel supply and conversion routes to minimize environmental impacts. R&D needs to be increased dramatically since it is meager compared to fossil fuels. Technology is evolving rapidly in many aspect of biomass energy which will accelerate its viability if greater resources are allocated to R&D. An additional factor will be the recognition by those working in this field that the development of biomass energy should be more closely integrated with other RE, local capacity building, etc.

Modernizing bioenergy will bring many benefits. Let us imagine, for example, that cellulose-based ethanol, or if ethanol was to be produced in many of the 100 sugarcane producing countries, becomes a commercial reality. Imagine if hundred of billions of dollars that currently flow into the coffers of a handful of nations, were to flow into the coffers of millions of farmers, most countries would see substantial national security, economic and environmental benefits. With so many millions involved in production of ethanol fuel, it would be impossible to create a cartel. With new drilling oil technology, we could make better use of existing resources and accelerate production, but not to expand oil reserves [99Lug].

The transportation system is more complex. The IC engines and oil-derived fuels have dominated the transportation systems for many decades. The IC engine has been so successful that until recently prospects for radical alternatives were not taken seriously and thus little RD&D had been directed to search for new alternatives. This has been further reinforced by the powerful and vested interest of two of the world's largest economic sectors: vehicles manufacturers and petroleum companies. It is only in recent years that the combination of technological, environmental and socio-economic changes is enforcing the search for new alternatives that could challenge the dominance of the IC. However, which alternative(s) will prevail is still unclear, given the present stage of development and the range of such alternatives under consideration, from which no clear winners have emerged so far. In the short term the main challenge will be to find sound alternatives to fossil fuels that can be used in the IC engine such as ethanol or biodiesel, currently in commercial use, while others such as hydrogen are emerging. In the longer term the challenge will be to find large-scale alternatives to fossil fuels that can be used both in existing IC engines and new propulsion systems.

Biomass data continues to be poor, despite considerable efforts to improve it. Consumption data often deals with the household sector, e.g. excluding data on many small enterprises. In particular, the modernization of biomass energy use requires a good data information base. Only a handful of countries have a reasonable production supply data, based mostly on commercial forestry practices when it comes to woodfuels. Often biomass resource assessment studies focus on residues potential or large countries, e.g. China, India, Philippines and Thailand.

Despite increased recognition, biomass energy does not receive the deserve attention from policy-makers and even less from educators. Let us finish with an illustrative quotation.

"Wood energy, like the oldest profession, has been around since time immemorial, like prostitution, it is ignored or regarded as an embarrassment by many decision makers at the national and international level. However, for about half of the world's population it is a reality and will remain so for many decades to come" [00Ope].

5.1.11 Policy recommendations and R&D needs

It is neither feasible nor desirable to propose a uniform and universal set of recommendations for biomass energy given its nature and differing levels of development in different parts of the world, in addition to socio-economic, cultural, geographic and climatic differences. Still, to facilitate the expansion of biomass energy, the following broad policy and R&D guidelines are recommended:

- Formulate clear policies to promote biomass energy on an equal footing with conventional energy sources, e.g. by internalizing the external costs of conventional energy to ensure that the polluter pays the full costs. This will have a direct benefit for bioenergy production.
- Ensure that know-how and technology transfer from the power industry and new transport fuels reach the developing countries.
- Support direct R&D to the most promising areas of bioenergy that increase the energy supply and improve the technological base.
- Allocate more R&D aimed at abating pollution (especially at local level) for bioenergy systems.
- Improve capacity building in bioenergy management skills, taking maximum advantage of existing local knowledge while encouraging multidisciplinary approaches. For bioenergy to have a proper role, institutional capacity building through education and training must be encouraged.
- Give greater recognition to the potential benefits of an integrated approach to RE development.
- Pay greater recognition to the potential contribution of bioenergy within agriculture. It is important to recognize that agriculture is more than just producing food and feed, and biomass energy can form an integral part of the agricultural development.
- Increase information dissemination efforts on bioenergy.

5.1.12 List of abbreviations

$	US-Dollar unless otherwise indicated
ABG	Air blown gasifier
Bgal	Billion gallons
Bl	Billion liters
BFBB	Bubbling fluidized bed boilers
BFBR	Bubbling fluidized bed reactor
BIG/CC	Biomass integrated gasifier/combined cycle
C	Carbon
CCGT	Combined cycle gas turbine
CEST	Condensing extraction steam turbines
CFBC	Circulating fluidized-bed combustion
CHP	Combined heat and power
DC	Direct combustion
EJ	Exajoules
FBC	Fluidized-bed combustion
FFVs	Flexible Fuel Vehicles
FxBC	Fixed fluidized-bed combustion
gal	US Gallon (1 US Gallon = 3.785 liters)
GHG	Greenhouse gas emissions
Gt	Giga ton
GtC	Giga ton carbon
GTCC	Gas turbine/steam turbine combined cycle
IBGT	Integrated biomass gasifier/gas turbine
IC	Internal combustion
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
IPCC	International Panel of Climate Change of the UN
LCA	Life cycle analysis
MAI	Mean annual increment
Mboe	Million barrels oil equivalent
Mt	Million ton
MtC	Million ton carbon
MtCe	Million ton carbon equivalent
Mtoe	Million ton oil equivalent
odt	Oven dry ton
PCFPPB	Pulverized coal-fired power plant boiler
Pf	Pulverized fuel
PFB	Pulverized fuel boilers
RD&D	Research, development and demonstration
RDF	Refuse-derived fuel
RE	Renewable energy
REW	Renewable Energy World
t or ton	Ton metric (1000 kg = 1 ton)

5.1.13 Main internet contacts

http://bioenergy.ornl.gov/reports/fuelwood/chap5.html
www.ebb-eu.org/stats
www.ieabioenergy.com
www.afdc.doe.gov/afv/biodiesel.html
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