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Renewable sources of energy, with special emphasis on biomass: progress and policies

Report of the Secretary-General*

SUMMARY

Biomass energy, or bioenergy, is experiencing a surge in interest stemming from a combination of factors: greater recognition of its current role and the future potential contribution of biomass as a modern fuel; its availability, versatility, and sustainability; its global and local environmental benefits; and the development and entrepreneurial opportunities. Significant technological advances and knowledge have recently accumulated on many aspects of biomass energy. However, despite these advantages and advances, bioenergy still faces many barriers stemming from economic, institutional and some technical factors. In many countries where bioenergy is currently so important, both on socio-economic and energy terms, few resources are allocated to biomass.

There is an enormous untapped biomass potential, particularly in improved utilization of existing resources, forest and other land resources, higher plant productivity, and efficient conversion processes, using advanced technologies. Much more useful energy could be economically derived from biomass than is derived at present. There is considerable potential for the modernization of biomass fuels to produce convenient and less polluting energy carriers such as electricity, gases and transportation fuels while continuing

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to provide for traditional uses of biomass. When produced in an efficient and sustainable manner, biomass energy has numerous environmental and social benefits: job creation, use of surplus agricultural land in industrialized countries, provision of modern energy carriers to rural communities of developing countries, improved land management, and a reduction of CO_2 and sulphur levels in the atmosphere.

Most biomass energy technologies have not yet reached a stage where market forces alone can make the adoption of these technologies possible. Costs are very specific, depending on a large number of variables ranging from raw material, management practices, type of technology, and environmental considerations. One of the principal barriers to the commercialization of renewable energy technologies, including bioenergy, is that current energy markets mostly ignore the social and environmental costs and risks associated with conventional fuel use, the hidden subsidies, the long-term costs of depletion of finite resources, and the costs associated with securing reliable supplies from foreign sources. Growing environmental and ecological pressures, combined with technological advances and increases in efficiency and productivity, are making biomass feedstocks more economically attractive in many parts of the world. Technological advances are opening up many new opportunities for bioenergy which were regarded only a few years ago as long-term prospects. These include: advanced steam cycle technology with cogeneration; cofiring with fossil fuels; integrated gasification/advanced technology; biocrude-fired combustion turbine technology; production of methanol and hydrogen from biomass; fuel cell vehicle technology etc. Energy demand will continue to grow although the pace will depend on population, economic growth, and technological advances. Bioenergy, both in its traditional and modern forms, can make a significant contribution to sustainable energy supply, socio-economic development and cleaner environments. However, for bioenergy to take advantage of these opportunities it needs to cease being considered the "poor man's fuel".

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INTRODUCTION

1. The Committee on New and Renewable Sources of Energy and on Energy for Development, at its first session (7-18 February 1994), requested the Secretary-General to prepare a report on renewable sources of energy: progress, policies and coordination. 1/ At its special session, the subject of the report was changed to renewable sources of energy, with special emphasis on biomass: progress and policies, 2/ and the change was approved by the Economic and Social Council at its substantive session in July 1995 in decision 1995/240. The present report, prepared in response to the Committee's request, is based on an extensive study commissioned by the Secretariat. 3/

I. BACKGROUND

2. The growing interest in bioenergy world wide as a modern energy carrier is due to:

(a) Awareness of its enormous potential; recognition of the increasing demand to provide modern energy to provide energy at accessible costs, particularly for rural and urban poor; the reflection of considerable technical gains of the past decade, mainly in the industrial world; the possibilities of converting biomass to other convenient "modernized" energy forms such as electricity and liquid and gaseous fuels, which can help spur rural industrialization and help to stem urban migration; recognition of the potential of biomass energy to diversify energy supplies and induce greater competition;

(b) Increasing concern with the environmental implications of fossil fuel use combined with the potential local and global environmental and ecological benefits arising from bioenergy when produced sustainably;

(c) Better perception of the potential local economic benefits of biomass; the realization that since biomass energy technologies are relatively small-scale and modular compared to most existing energy facilities, the pace of development and introduction of bioenergies can be speeded up if the right conditions exist; employment opportunities (e.g., in Brazil the modern bioenergy sector employs about 1 million people);

(d) Economic attraction: despite low oil prices, a combination of factors (concern with the environment, sustainability, technological advances, increasing energy demand etc.);

(e) New possibilities for reducing governmental subsidies to farmers through economically viable bioenergy production on surplus land and a growing interest in using new crops for other products, in addition to food, and for new uses of established crops, reflecting growing environmental and sustainability pressures.

3. None the less, despite this growing interest, bioenergy still faces difficulties because of:

(a) Inadequate political, financial, and institutional support;

(b) Insufficient funding for research and development and demonstrations, particularly in the developing countries;

(c) Exclusion of external costs and the non-monetary benefits in economic evaluations of energy which place biomass energy on an unequal footing compared to conventional energy sources;

(d) Low oil prices;

(e) Varied and sometimes unpredictable nature of biomass energy sources and uses;

(f) The perception that land availability could be a problem by competing with food production.

A major additional problem is that many biomass energy sources, particularly woodfuels, are still obtained free or at low cost, especially in developing countries; therefore there is little incentive to improve energy efficiency or to find alternative energy sources unless they can be provided on an equal delivered cost basis. Thus, improving biomass fuel efficiency has not always been a primary concern, and other non-energy factors such as convenience may be priorities.

4. One of the problems with perception of the role of biomass energy is the lack of reliable data on country, regional and global use. The Food and Agriculture Organization of the United Nations (FAO) statistics indicate that only 6 per cent of the world's energy is derived from biomass, but other estimates claim about 14 per cent (equivalent to 55 exajoules (EJ)). Such discrepancies lead energy planners to dismiss the importance of bioenergy. This can be especially harmful at the country level where sometimes 80-90 per cent of the country's energy could be derived from biomass.

II. ENERGY POTENTIAL OF BIOMASS RESOURCES

A. Historical perspective

5. Four broad categories of biomass use can be distinguished:

(a) Basic needs - food fibre, etc.;

(b) Energy - domestic and industrial;

(c) Materials - construction etc.;

(d) Environmental and cultural - the use of fire etc.

Biomass use through the course of history has varied considerably, greatly influenced by two main factors: population size and resource availability.

6. Wood and charcoal fuelled industrial development until well into the nineteenth century in Europe. In the United States, forests played a particularly key role in the socio-economic development of the country. From the seventeenth to the early twentieth century, wood was the most valuable raw material for American life and livelihood. Today there are still many biomass-based manufacturing and service industries around the world, ranging from brick- and tile-making, steel manufacture, metal working and weaving to bakeries, food processing and restaurants. In India, for example, around 50 per cent of rural industrial production is biomass-driven. In the United Republic of Tanzania over 2 Mt of woodfuel were consumed by such industries in 1992. Most rural industries will continue to use biomass as their main source of energy in the short and medium term. A major problem is that the techniques used are usually highly energy inefficient.

7. Biomass energy use, particularly in its traditional forms, is difficult to quantify, thus creating additional problems. There are two major reasons for this. One is that biomass is generally regarded as a low-status fuel, the "poor man's fuel", and thus rarely finds its way into official statistics. When it does, it tends to be downgraded. Traditional uses of biomass (fuelwood, charcoal, animal dung, and crop residues) are inaccurately associated with problems of deforestation and desertification. In central Zambia, the main charcoal-producing area of the country, there is no evidence of land degradation due to deforestation caused by woodfuel harvesting, either for firewood or charcoal. The second reason is that since biomass is a dispersed energy source and inefficient in use, little final energy is obtained. Charcoal, for example, is a very important fuel in many developing countries, but charcoal yields are notoriously low - e.g., about 12 per cent in Zambia, and 8-10 per cent in Rwanda, on a dry weight basis. There is, however, a great potential for increasing charcoal production efficiency: in Brazil the best kilns have an efficiency of about 35 per cent.

8. What distinguishes modern biomass energy carriers from their traditional forms is their ability to produce clean and convenient energy with greater efficiency, by applying modern technology, often as by-product of another major activity such as the generation of electricity from sugarcane bagasse or forest/wood residues in the pulp and paper industry. In the United States, for example, most biomass installations are independent power and cogeneration systems (in the range of 10-25MW), many based alongside pulp and paper mills which have abundant residue supplies. By the year 2020, between 5 and 10 per cent of power generation capacity in the United States is expected to come from these types of plants. Traditional bioenergy, in contrast, is mostly used in small-scale applications and often forms part of the informal and non-monetarized local economy.

9. The relatively poor image of biomass is now changing for three main reasons:

(a) Considerable efforts over recent years to present a more balanced and realistic picture of the existing use and potential of biomass through new studies, demonstrations, and pilot plants;

(b) Increasing utilization of biomass as a modern energy carrier, particularly in industrialized countries;

(c) Increasing recognition of the local and global environmental advantages of biomass and of the measures necessary to control net CO_2 and sulphur emissions.

10. Contrary to a general view, biomass utilization worldwide remains steady or is growing, owing to population growth and urbanization and improvement in living standards. As living standards improve, many people in rural and urban areas in developing countries convert to different uses of biomass (charcoal, building materials, cottage industries etc.). Thus urbanization does not necessarily lead to a complete shift to fossil-based fuels. In the Thazi and Meiktila districts of Myanmar, population growth, together with the prosperous development of cottage industries, has resulted in a substantial increase in woodfuel consumption in recent years. In Zambia and Rwanda urbanization has led to a considerable increase in the use of fuelwood in the form of charcoal. In Madagascar, it was found that with increased living standards, urban dwellers continued to rely on woodfuel and charcoal.

B. Present potential

11. Bioresources are potentially the world's largest and sustainable source of fuel - a renewable resource comprising 220 billion oven dry ton (odt) (about 4,500 EJ) of annual primary production. The annual photosynthetic storage of energy in biomass is 8-10 times more than the present energy use from all sources. The problem is not availability but rather the sustainable management and delivery of energy to those who need it. In practice, only a few types of biomass feedstock can seriously be regarded as potential sources of energy, due to various economic and environmental constraints. Residues from forestry and agriculture are invaluable as immediate and relatively cheap energy resources to provide the initial feedstock for the development of bioenergy industries. Since they are also frequently an environmentally acceptable way of disposing of unwanted and polluting wastes, their use must encompass environmental sustainability. Thus the ash from burners and effluent from digesters can be returned to the land as fertilizers. The energy content of potentially harvestable residues is about 93 EJ/yr worldwide. Assuming that only 25 per cent of this is realistically recoverable, this could provide 7 per cent of the world's energy.

12. While residues can provide an important kick-start for the bioenergy industry, the development of large-scale energy production from biomass will probably rely in the future on specifically grown energy crops such as sugarcane, miscanthus, switch grass, and trees (particularly short-rotation forestry). Biomass productivity must be improved, since it is generally low - much less than 5 t(dry weight)/ha/yr for woody species, without good management. It is now possible, with good management, continued research, and planting of selected species and clones on appropriate soils, to obtain 10-15 t/ha/yr in temperate areas and 15-25 t/ha/yr in tropical countries. Record yields of 40 t/ha/yr have been obtained with Eucalyptus in Brazil and Ethiopia. High yields are also feasible with herbaceous (non-woody) crops; for example, in

Brazil, the average ethanol yield from sugarcane has risen from 2,400 l/ha (1976/77) to 5,000 l/ha (1993/94).

C. Future biomass energy scenarios

13. In the past few years a number of global energy scenarios have been published, most of which include substantial roles for energy efficiency and renewable energy; some have studied biomass in detail and incorporated large roles for bioenergy. The Renewable Intensive Global Energy Scenario proposes a significant role for biomass in the next century. It concludes that by 2050 renewable sources of energy could account for three fifths of the world's electricity market and two fifths of the market for fuels used directly. Within this scenario biomass should provide about 38 per cent of the direct fuel use and 17 per cent of the electricity. Detailed regional analyses show how Latin America and Africa may become large exporters of biofuels in the future.

14. The Environmentally Compatible Energy Scenario developed by the International Institute of Applied Systems Analysis predicts that primary energy supply will be 12.7 gigatons of oil equivalent (Gtoe) (533 EJ) by 2020 of which biomass energy would contribute 12 per cent (62 EJ), derived from wastes and residues, energy plantations and crops, and forests. This excludes traditional uses of non-commercial biomass energy as fuelwood in developing countries. The Fossil-Free Energy Scenario of Greenpeace forecasts that in 2030 biomass could supply 24 per cent (91 EJ) of primary energy supply (total = 384 EJ) compared to today's 7 per cent (22 EJ) out of a total of 338 EJ. The biomass supply could be derived equally from developing and industrialized countries.

15. The World Energy Council examined cases of global energy supply to 2020, spanning energy demand from a "low" (ecologically driven) case of 475 EJ to a "very high" case of 722 EJ, with a "reference" case total of 563 EJ. In the ecologically driven case, traditional biomass could contribute about 9 per cent of total supply, while modern biomass could supply an additional 5 per cent of the total equal to 24 EJ. New renewables combined (modern biomass, solar, wind etc.) could supply 12 per cent of the total. In the high growth case these contributions could be 8 per cent and 5 per cent, respectively, of a higher total supply. The International Energy Agency (IEA) examined world total primary energy demand for the next 15 years and estimated a need for 486 EJ by 2010, compared to 330 EJ today. Most of the increased demand is predicted to arise in countries that are not members of the Organisation for Economic Cooperation and Development (OECD). In the IEA analysis biomass is part of "coal and other solid fuels" for which worldwide demand is predicted to rise by 2.1 per cent per annum. In the Conventional Development Scenario, a conservative view of bioenergy is taken: it represents about 4-5 per cent (36-45 EJ) of the global primary energy supply (over 900 EJ) in the year 2050. An optimistic scenario (GREENS) proposes that biomass could supply 75 per cent of the world's energy as soon as 2015. In the Conventional Wisdom Scenario, electricity from energy crops grown on land set aside, plus 10 per cent of land in the developing countries, could generate 46 EJ (33 per cent) of a total of 136 EJ in 2050, or 12 per cent of the estimated primary fossil fuel and nuclear energy.

16. Shell International Petroleum has developed two scenarios. In the Sustained Growth Scenario, an abundant supply of energy is provided at competitive prices, as productivity in supply keeps improving in an open market context. Global average energy per capita increases from about 13 barrels of oil equivalent (boe) (75 gigajoules (GJ)) today to 25 boe (143 GJ) by 2060, and 40 boe (229 GJ) in 2100. By 2020 new renewables, particularly biomass, photovoltaic and wind, become major players, representing about 10 per cent (80 EJ) of the world's energy market. By 2050 renewables provide between 40 and 50 per cent of the world's energy requirements. This model also envisages that by 2060, about 200 EJ of primary energy could be obtained from 400 Mha of biomass plantations, with an average productivity of 25 t/ha. In Shell's Dematerialization Scenario, human needs are met through technologies and systems requiring a much lower energy input. Global average energy per capita remains at 13 boe annually (total energy supply is 1,200 EJ, compared to 400 EJ today) and reaches 17 boe (57 GJ) by 2100. In this model, energy conservation technologies become economically more effective, with biomass benefiting from major advances in technology.

17. What is evident from examining all these scenarios is that biomass could be a major contributor to future energy supplies, especially as a modern fuel, and still play an important role as a traditional fuel, mainly in developing countries. How much bioenergy will contribute in the next century will depend on many factors, which are implicit in the various scenarios proposed in each study.

III. ENVIRONMENTAL AND SOCIAL IMPACTS

A. Environmental

18. Human dependence on biomass has affected the environment in various ways, depending on the scale of use and environmental sustainability, although the extent of such influence is unknown. Some authors have suggested that pre-industrial societies were able to manipulate the environment on a vast scale. Regardless of the degree to which pre-industrial activity has affected the global carbon cycle, even small non-industrialized human populations can alter the landscape in ways that may require decades or centuries to correct. Today biomass use can have various kinds of impact on the environment, but a major concern is CO_2 emissions from biomass combustion, both deliberate (usually) and accidental. Biomass energy is CO_2-neutral when produced and used sustainably. In practice, however, this is not always the case since biomass energy is often used in a very inefficient non-renewable manner in many rural areas of developing countries. There are three main ways in which biomass contributes directly to CO_2:

(a) Traditional uses of biomass energy present two main, related problems - very low efficiencies, which result in excessive consumption of biomass in order to produce a small amount of useful energy; and often very low cash cost, which results in little incentive to improve efficiency or to replace the trees and other biomass sources. The result is that far more biomass is removed than replanted or allowed to regrow;

(b) Tropical deforestation, particularly for non-energy uses;

(c) Tropical grasslands burning; this is also a significant source of greenhouse gas (GHG) emissions. Large areas are burned every year, some 750 Mha in Africa alone.

1. The role of biomass in mitigating greenhouse gases (forest alternatives)

19. There are various measures which are available in order to slow, stabilize or reduce GHG emissions. There are three strategies for using forests to reduce atmospheric CO_2 levels: preserving existing forests; planting trees to create sinks to sequester CO_2; and substituting fossil fuels directly by biomass fuels. No option is necessarily cheap or easy.

20. Preserving existing forests seems to be the most sensible option in the short term. The forests will thus continue to act as a reservoir of carbon, while at the same time reducing the deforestation rate and resulting in less CO_2 being emitted to the atmosphere. However, there are at least two problems to this option: socio-economic pressures on existing forests makes it difficult to implement, particularly in developing countries; and mature forests grow slowly and thus less CO_2 is absorbed in comparison to fast-growing trees.

21. Reforestation with fast-growing trees on non-agricultural lands has been widely proposed as a major way to sequester CO_2. As trees grow, they remove CO_2 from the atmosphere and thus slow down the CO_2 build-up. This is perhaps the most widely proposed strategy so far, since it can also provide important ancillary benefits such as soil and water conservation, commercial products, biodiversity etc. However, it is being increasingly questioned as its complexity becomes more apparent. Implementation would prove difficult, unless there were substantial and long-term guaranteed incentives for local people to participate actively. Forest plantations can accumulate large amounts of biomass, particularly in the tropics where experimental productivity as high as 70 t/ha/yr dry biomass has been reported. The figures often quoted for a well managed forest range from 15 to 25 t/ha/yr of dry biomass. On a global scale, 10 t/ha/yr may be more realistic, although over the coming years productivity is likely to increase quite significantly with the application of modern plant management and breeding techniques.

22. There have been a number of studies to determine the potential of reforestation to sequester CO_2, but they must be treated as rough guides, given the difficulties involved in providing reliable estimates of such a long-term nature and given that plantations of various types have been notorious for their many failures. Forest plantations have grown from about 80 Mha in the mid 1960s to about 130 Mha in 1990, but this is small in comparison to the estimated 14-20 Mha being deforested annually. (In the past few years the deforestation rate seems to have declined slightly.) It is possible to reduce global CO_2 emissions substantially by adopting various measures such as optimal ecosystem management practices and use of bioenergy. The Enquete Commission (Bonn) states that if ecological, economic, organizational, and socio-cultural constraints are taken into consideration, a rough estimate indicates a potential of C fixation

of about 2.6 billion ± 1.1 billion tC/year by afforesting available land, and a further 0.1-1.1 billion tC could be saved by the use of bioenergy (see table 1).

Table 1. Current and potential future impact of human activities on forests and their carbon budget

	Annual felled area as percentage of total usable forest area	Current stand development (Mha/yr)	Potential C fixing due to afforestation (GtC/yr)	Potential additional C reduction by use of wood as energy (GtC/yr)
Boreal forests	c. 0.5	-0.7[3]	0.07±0.02	-
Temperate forests	c. 2.5	+1.4[4]	0.54±0.2	0.1-0.9
Tropical forests	c. 0.5	-17.0	2.0±0.9	0.0-0.2
Total	c. 0.8	-16.7	2.6+1.1	0.1-1.1

Source: German Bundestag Enquete Commission, Protecting Our Green Earth. Twelfth report. (Bonn, Economica Verlag, 1995), table 6.13.

This will be particularly positive if areas have been unforested for long periods. If all potential available land (150-1,200 Mha) were to be afforested, the potential for C fixation would be in the range of 1 billion-7.5 billion tC/year.

23. A simple model has been constructed of C sequestration during forest growth and the fate of that C when forests are harvested and used as fuel to replace fossil fuels. It considers that trees are equally effective in preventing the CO_2 build-up whether they remove a unit of C from the atmosphere or whether they supply a sustainable source of energy that substitutes for a unit of C discharged by burning fuels. The main conclusions are that for forests with large standing biomass and low productivity, the most effective strategy is to protect the existing forest; for land with little standing biomass and low productivity, it is best to replant or otherwise manage the land for forest growth and C storage, and where high productivity can be expected, it may be best to manage the forest for a harvestable crop and to use the harvest with maximum efficiency either for long-lived products or to substitute for fossil fuels.

2. Carbon sequestration versus fossil fuel substitution

24. Direct substitution of fossil fuels by biomass appears to be a more effective strategy for offsetting CO_2 emissions from fossil fuel combustion, since greater benefits might be obtained. If biomass is grown for energy with the amount grown equal to that burned for a given period, there would be no net build-up of CO_2 since the amount released in combustion would be compensated for by that absorbed by the biomass during photosynthesis. For example, if the

conversion efficiencies are equal, then each GJ of biomass substituted for fossil fuel would reduce emissions by the C content of one GJ of fossil fuel displaced - 0.014 tC, 0.019-020 tC, and 0.023-0.025 tC for natural gas, petroleum, and coal, respectively. The substitution of energy from biomass for non-renewable energy is gaining recognition. Thus tax incentives are available in the United States of America, Sweden, Denmark etc. for biomass-fuelled heat and electricity utilities. In India, where between 1980 and 1992 about 17 Mha were afforested mainly to meet the fuelwood needs of local communities, the annual woody biomass production was estimated at 58 Mt in 1993. Considering, that the annual fuelwood demand in India is about 227 Mt, much of it unsustainably harvested, the contribution from plantations is quite significant. In China also about 6 Mha have been afforested to meet fuelwood requirements. (However, the biomass production from such afforestation is still small compared to annual coal use.)

3. Estimated costs for reducing CO_2 emissions

25. Cost estimates for reducing CO_2 emissions vary quite considerably - often by a factor of two or three - due to the many variables involved, ranging from productivity to socio-economic and political issues. The cost of offsetting CO_2 emissions by sequestering C in trees is directly related to the cost of growing the biomass. Forest plantation costs can vary a great deal, since they tend to be very site-specific and are influenced by a large number of factors - biological, topographical, transport etc. Cost estimates for afforestation are still controversial and poorly documented; a figure of $400/ha is often quoted in the literature. But it might be four or five times higher if maintenance, protection etc. are added over the lifetime of the forest. In France and the United Kingdom, afforestation costs are $2,000-$2,500/ha, and in Germany, about $12,500/ha in 1993.

4. Environmental and ecological concerns with forest plantations

26. There are concerns as to the short-term and long-term environmental effects of large-scale use of energy plantations. However, recent studies indicate that any potential negative environmental effects are largely dependent on management practices. For bioenergy to have such a large-scale contribution, its production, conversion, and use must be sustainable and environmentally acceptable and also be accepted by the public. If plantations were to replace natural forests, there would be destructive environmental effects and negative effects on carbon inventories. Thus this should be avoided. On the other hand, forestry projects established on degraded land or abandoned cropland can have numerous positive environmental results. Reforestation/afforestation of such land can improve the soil structure, soil organic matter and nutrients, reduce run-off and increase soil water storage, increase local rainfall and modify local temperatures, increase biodiversity and preserve wildlife habitats, reduce pressure on natural forests, create windbreaks, and, of course, store carbon. Recent experience with the United States Conservation Reserve Program showed that the erosion rate declined 92 per cent on 14 Mha of highly erodible cropland taken out of annual production and planted with perennial grasses and trees. Care in species selection and good plantation design and management can be

helpful in controlling pests and diseases, rendering the use of chemical pesticides unnecessary in all but special circumstances. Good plantation design includes areas set aside for native flora and fauna to harbour natural predators for pest control, and perhaps blocks characterized by different clones and/or species. If a pest attack breaks out in a block of one clone, a now common practice in well managed plantations is to let the attack run its course and let predators from the set-aside area help halt the pest outbreak. Well managed plantations in Brazil now leave 20-30 per cent of the area (required by law) in a natural/undisturbed state. Establishing and maintaining natural reserves also enhances biodiversity; however, preserving biodiversity on a regional basis will require land-use planning in which natural forest patches are connected via a network of undisturbed corridors (riparian buffer zones, shelterbelts, and hedgerows between fields), thus enabling species to migrate from one habitat to another.

27. Attention must be given to long-term soil fertility, which also involves soil management. For short-rotation forestry, it will usually be desirable to leave leaves and twigs in the field since nutrients tend to concentrate in those parts of the plant. Also, the mineral nutrients recovered as ash at the energy conversion facilities should be returned to the site. Species can be selected for efficiency of nutrient use; in addition, either selecting a nitrogen-fixing species or intercropping the primary crop with a N-fixing species can make the plantation self-sufficient in nitrogen. The promise of intercropping strategies is suggested by 10-year trials in Hawaii, where yields of 25 t/ha/yr have been achieved without annual N fertilizer additions when Eucalyptus is interplanted with N-fixing Albizia trees. Biodegradable agrochemicals should be used whenever possible, and their application should be carefully planned to match the needs of the plants. Furthermore, careful water management will reduce the risks of water pollution from run-off and make optimum use of rainfall in dry areas. Good fire management practices must also be included.

B. Social

28. Three major social implications of bioenergy production are land use and availability, food versus fuel, and employment generation.

1. Land use and availability

29. Many studies have been carried out on land availability, and they give very wide-ranging results, depending on sources of data and assumptions used. There are large areas of degraded and abandoned lands in the tropics which could benefit greatly from the establishment of environmentally sustainable biomass plantations. Land availability is perceived as a constraint to large-scale production of biomass; however, there are considerable areas potentially available even under the present production systems. In the United States, farmers are paid not to farm about 10 per cent of their land, and in the European Community about 15 per cent of arable farmland is being "set aside". Apart from over 30 Mha of cropland already set aside in the United States to reduce production or conserve land, another 43 Mha of croplands have high erosion rates and a further 43 Mha have "wetness" problems, which could be eased

with a shift to various perennial energy crops. In the European Community, at least 15-20 Mha of good agricultural land is expected to be taken out of production by the year 2000/2010. If all this land were used to plant trees, it would represent an annual sink of 90-120 MtC for the near future. Alternatively, this area of land could provide 3.6-4.8 EJ/yr of biomass energy, displacing 90-120 Mt of carbon emissions from coal, 72-96 Mt from oil, or 50-67 Mt from natural gas. It has been estimated that in Western Europe, if 10 per cent of useable land (33 Mha) and 25 per cent of recoverable residues were used, biomass could provide 9.0-13.5 EJ of energy, which represents about 17-30 per cent of projected energy requirements in 2050.

30. In tropical countries there are large areas of deforested and degraded lands that could benefit from the establishment of bioenergy plantations. An analysis of 117 tropical countries suggested that 11 countries were suitable for expansion of the forest area up to 553 Mha. Another study found that in 50 tropical countries, 67 Mha could be realistically converted to plantations over the next 60 years, more than 200 Mha could be regenerated, and a further 63 Mha are available for agroforestry. The land that would theoretically be needed to meet all of present energy consumption with biomass (a very unlikely scenario) has been estimated. Assuming a productivity of 12 oven dry tons (odt)/ha/yr, and the use of recoverable residues (25 per cent of potentially harvestable residues), it was found that 950 Mha would be needed to grow biomass energy crops to substitute for all fossil fuels in industrialized areas, while developing countries would require 305 Mha. Therefore, on a global scale, there is enough land available to allow biomass to make a significant impact on atmospheric carbon levels and energy production without affecting food production.

2. Impacts on food production: the food vs. fuel issue

31. "Food versus fuel" is an old, controversial and complex issue whose detailed analysis is beyond the scope of this paper. On a global scale there is available land; also biomass energy crops can be managed for minimum water and nutrient inputs to a greater extent than food crops. There are people who state that the doom and gloom about declining food production is based on several misconceptions, and the following need to be carefully considered:

(a) Taken as a whole, considerable progress has been made in food supply since the 1950s - from 300 kg of food per capita in the 1950s to 350 kg per capita in the 1980s;

(b) The decline in world cereal output has resulted from the cut in grain production in the United States and the European Community, rather than population growth;

(c) Generally, world food production has been keeping ahead of population growth, and diets are now more diverse; land withdrawn from cereals production has been converted to the production of higher value foods;

(d) Average per capita cereal production is a poor measure of global food availability. Even if per capita production increases, per capita food consumption will decline because population growth will come mostly from the poorer countries;

(e) The two most populous countries, China and India, have kept food production ahead of population growth. India provides a good example of changing trends in food production, energy, population, and environment - in 1995 it had over 30 Mt of surplus grain although it halted deforestation, increased tree cover and maintained the same cultivated area.

32. The FAO agroecological zone database was used to estimate the potential land available after supplying food in 2025. Theoretically, if biomass was produced at 10 T/ha on "remaining land", biomass could provide sufficient energy for the developing countries. In Africa, for instance, it seems that social and cultural factors - e.g., the key role that many women play in food production - will be vital in trying to reverse the downward spiral caused by the interlinked factors of overpopulation, poor agricultural productivity and environmental degradation. An extensive study of global land and food in the next century comes to an "encouraging conclusion" with qualified caveats, depending on institutional arrangements, sustainable agriculture and land pressures. Africa and the Middle East are highlighted as being most vulnerable.

33. It should be noted that both food and fuel are important requirements that need not compete, particularly when planning ensures ecological conservation and sustainability of production methods. Forestry policies and programmes such as agroforestry and integrated farming systems can in fact improve food security by providing food (from the tree directly and from animals in the habitat provided), fodder, energy, and income for food purchase. For example, in Brazil where the area used for ethanol from sugarcane represents less than 0.2 per cent of total land area, crop rotation in sugarcane areas has led to an increase in certain food crops, while some by-products of the industry are used as animal feed.

3. Employment generation

34. Employment opportunities have been heralded as a major advantage of biomass because of the many multiplying effects which help to generate more economic activity and help strengthen local economies, particularly in rural areas. In the United States, the National Wood Energy Association has estimated that the country’s 6,500 MW of biomass power sustains 66,000 direct jobs and could sustain as many as 284,000 jobs by 2010. The Wisconsin Energy Bureau recently found that the use of renewable energy generates about three times more jobs, earnings and sales output in Wisconsin than that of the same level of imported fossil fuels and investment. Given a 75 per cent increase in the state’s renewable energy use, the Bureau found that Wisconsin would realize more than 62,000 new jobs, $1.2 billion in new wages, and $4.6 billion in new sales. Another study completed recently in Vermont showed that the wood energy industry generated almost 53,000 jobs in the northeast and $2.9 billion in income. Wood energy use annually eliminates the need for about 1 billion gallons of oil, 65 per cent of which would be imported from outside the region. The region’s wood energy activities pay an estimated $46 million in state and local taxes and $355 million in federal taxes annually.

35. In the European Community as a whole, according to the Madrid Declaration (1994), the substitution of 15 per cent of conventional primary energy demand by renewable energy sources by the year 2010 could create between 300,000 and 400,000 new jobs, increasing the turnover of the renewable energy industry to 6 billion ECU, and avoid 350 Mt of CO_2 emissions. It has been estimated that if the European Community were to implement a large-scale bioenergy sector, about 7 million new direct and indirect jobs could be created within the next 40 years. In the United Kingdom a preliminary study has also shown the potential for job creation, particularly in locations suffering from high unemployment. By the year 2005 some 48,700 jobs could be generated in renewable energy, of which 11,600 would be net jobs generated in the economy. Another well known example is Brazil, where the ethanol-based industry supports about 700,000 jobs and the charcoal-based sector, about 200,000 direct jobs. Charcoal-making provides considerable employment in rural areas and is a major activity, particularly in Africa. The value of the charcoal market for 26 sub-Saharan countries is over $1.8 billion annually. In Kenya and Cameroon it employs 30,000 people, and in Ivory Coast, some 90,000.

IV. TECHNOLOGY TRENDS AND MODERN BIOENERGY

A. Technology trends

36. Certain emerging and improved biomass technologies have immediate potential applications, such as integrated biomass gasifier/gas turbine systems for power generation; improved techniques for biomass harvesting, transportation and storage; gasification of crop residues such as rice husks; briquetting; treatment of cellulosic materials by steam explosion, which may be followed by biological or chemical hydrolysis to produce ethanol or other fuels; cogeneration technologies; biocrude technology; co-firing technology; fuel cells technology, methanol and hydrogen from biomass; and improvements in small Sterling engines capable of using biomass fuels efficiently. The main trends of recent years are summarized below.

1. Direct combustion/gasification of biomass to produce heat, steam and electricity

37. Considerable research, development and demonstration efforts have gone into gasification since it is regarded as one of the most promising areas. Advances have been made in designing and improving furnaces and boilers to burn different types of biomass - e.g., furnaces such as the spreader-stoker types fuelled by wood and bark, suspension furnaces, and fluidized bed combustion systems. Unfortunately insufficient attention has been paid to those aspects that consider the needs of rural industries in developing countries - e.g., low-cost, efficient, easily operated furnaces and kilns to provide entrepreneurial opportunities. In the household energy sector, a notable achievement has been the installation of millions of improved cooking stoves (for example, some 129 million in China from 1982 to 1992, 0.78 million in Kenya, and 0.2 million in Burkina Faso and Niger) with an average energy saving of 20 per cent and in some cases reaching over 60 per cent.

38. The present biomass combustion power plants have efficiencies in the range of 15-20 per cent, with electricity costs of $0.05-0.08/kWh. In contrast, the advanced power generation cycles have potential efficiencies of 35-40 per cent with electricity costs of $0.045-0.055/kWh. The most important technical concepts being developed for biomass power generation include direct firing of biomass, co-firing of biomass with coal, gasification, and pyrolysis of biomass to produce biocrude, either in liquid or gas forms.

39. Simple open-cycle gas turbines discharge the hot exhaust gas directly to the atmosphere, which is very wasteful (around 33 per cent overall efficiency) when the heat can be used to produce steam in a heat recovery steam generator. The steam can then be used for heating in a cogeneration system, for injecting back into the gas turbine and thereby improving power output and generating efficiency - known as a steam-injected gas turbine (SIGT) cycle (40 per cent efficiency) or, for producing more electricity, through a steam turbine, a gas turbine/steam turbine combined cycle (GTCC) (48 per cent efficiency). Therefore, advanced gas turbines can have far greater efficiencies than conventional steam turbines, and there is also considerable potential for continuing technological improvements; and capital costs are lower.

40. Much of the work on coal gasifier/gas turbine systems is directly relevant to biomass integrated gasifier/gas turbines (BIG/GT) and GTCC. BIG/GTCC technology uses either low pressure or pressurized gasification. Pressurized BIG/GTCC is more efficient but is likely to be more capital-intensive below a certain capacity range. Biomass is easier to gasify than coal because it is more reactive and has a very low sulphur content. Also, BIG/GT technologies for cogeneration or stand-alone power applications have the promise of being able to produce electricity at a lower cost in many instances than most alternatives; this includes large centralized, coal-fired, steam-electric power plants with flue gas desulphurization, nuclear power plants, and hydroelectric power plants. Efficiencies of 40 per cent or more will be demonstrated in the mid-1990s, and by 2025 they could reach 57 per cent using gasification technologies being developed for coal. The sugarcane industries that produce sugar and fuel ethanol and the pulp and paper/timber industries are particularly promising targets for near-term applications of BIG/GT technologies. BIG and GTCC technology will be commercially available by the year 2000. A BIG/GTCC system is being built at Vaernamo, Sweden, with a capacity of 6 MWe + 9 MW combined-cycle district heating cogeneration. A 30 MWe BIG/GTCC demonstration plant is due for commissioning in 1997 or soon thereafter in north-east Brazil at a total cost of $75 million, of which $30 million is a grant from the Global Environment Facility. As much as 200 GW of potential BIG/GTCC capacity has been identified from future plantations in north-east Brazil. The European Community has plans to implement commercial biomass gasification projects - IGCC power plants of 8-15 MWe by late 1990s, 20-30 MWe by the year 2000, 50-80 MWe by 2005. The plants must be biomass-based and must be able to use high-yield energy crops, demonstrate advanced energy conversion systems, and be environmentally friendly. Three demonstration gasification projects are already receiving financial support from the European Union - an 11.9 MWe plant in Italy, an 8 MWe in the United Kingdom, and a 7 MWe district heating cogeneration system in Denmark. A further 15-30 MWe plant is to be built in Haarlem (Netherlands). In addition, two other projects are ongoing in the United States, with financial support from the Department of Energy - a 3-5 MWe air-blown pressurized, bubbling fluidized-

bed gasification of bagasse for gas turbine power production in Hawaii, and a 200 t/day biomass (45 Mwe) plant in Burlington, Vermont.

2. Production of liquid fuels

41. Ethanol from crops such as sugarcane and maize are the main feedstock. In ethanol production, advances have taken place in continuous fermentation (the Melle-Boinot and Biostil processes); simultaneous saccharification and fermentation; anaerobic fermentation; use of bacteria; heat recovery in the distillation process; and better use of by-products - e.g., bagasse which is used as animal feed and for electricity cogeneration. Two countries that cogenerate electricity from bagasse are Brazil and Mauritius. Brazil has been using bagasse to raise steam for on-site processes for centuries, but very inefficiently. Because large amounts of bagasse were available, there was little incentive to improve energy efficiency since disposing of the surplus bagasse was often a major problem. Recently many sugarcane distilleries have become energy self-sufficient, and some are selling electricity to the grid. With the development of SIGT, electricity generation in the sugar mill or alcohol distillery of the future may become one of its main activities.

3. Production of charcoal

42. Significant advances have been made in some areas of charcoal technology - improved carbonization techniques and improved kilns with better energy efficiency; better use of by-products; improved blast furnaces; integrated charcoal-based steel plants etc. A major advance has been the development of sustainable natural forest harvesting and biomass plantations and greater awareness of the environmental implications of such production systems. For example, in 1993 about 43 per cent of the charcoal produced in Brazil, mostly used in pig-iron, steel, cement, and metallurgy industries, originated from plantations, compared to only 12 per cent in 1978. However, industrial charcoal consumption is progressively being replaced by imported coke, with negative global environmental effects; also little use is being made of charcoal by-products.

4. Thermochemical conversion of biomass

43. In this field, advances include low temperature pyrolysis, fast pyrolysis, direct catalytic liquefaction with more effective heat transfer to a liquid phase, and reduction in reactor times.

5. Anaerobic digestion of biomass residues, wastes and dung

44. The increasing commercial interest in this area is partly due to environmental considerations (coupled with energy supply), in both developed and developing countries. This has been helped by financing incentives, energy efficiency advances, and dissemination of the technology; the training of personnel, particularly in China and India, has also improved. During the past few years, this technology has been carefully examined in Denmark, which has

been at the forefront of demonstrating large commercial biogas plants for treating manure and for heat and power generation. A significant change in biogas technology has been a shift away from energy efficiency towards more environmentally sound technology, which allows for the combination of waste disposal with energy and fertilizer production. Biogas technology is reaching technical and economic maturity in many situations.

6. Technology-related policy developments

45. Non-technical issues which have recently gained attention include environmental and ecological factors (carbon sequestration, reforestation and revegetation); biomass as a CO_2 neutral, low-sulphur, replacement for fossil fuels; greater recognition of the importance of biomass energy, particularly modern biomass energy carriers, at the policy and planning levels; greater recognition of the difficulties of gathering good and reliable biomass energy data, and efforts to improve data provision for energy planning; studies on the detrimental health effects of biomass energy, particularly from traditional energy uses; and greater awareness of the need to internalize the externality costs of conventional energy carriers, so as to place them on more equal terms with alternative energy sources.

B. Modern uses

1. Developing countries

46. In India, gasification has been one focus of attention because of its potential for large-scale commercialization to meet a variety of energy needs, such as irrigation pumping and village electrification, captive industrial power generation and grid-fed power, from energy plantations. Recent estimates put the potential of biomass-based gasification power generation in India at 17,000 MW and the potential for using sugarcane residues at 3,500 MW.

47. Mauritius is dominated by the production of sugar, which represents around 88 per cent of the cultivatable area. About 10 per cent of total energy requirements in the country are met by bagasse-fired generation of power and steam in the sugarcane industry. The theoretical potential has been estimated at 2,500-3,500 GWh at conversion efficiencies of biomass to electricity of 30 per cent and 40 per cent, respectively.

2. Industrialized countries

48. Austria obtains about 13 per cent (147 picajoules (PJ)) of its primary energy from wood - a sixfold increase in 15 years. A comprehensive study of the potential of bioenergy indicates that bioenergy could double, to 280 PJ, by the year 2015. The total investment would be around 600 million ECUs, and between 10,000 and 15,000 new permanent jobs could be created.

49. Bioenergy contributed about 7 per cent (19 PJ) of Denmark’s energy in 1994. The potential is estimated at 127 PJ, or 16 per cent of Denmark’s gross energy

consumption, or about 140 PJ if set-aside land (about 230,000 ha) were also used for bioenergy. In June 1993, the Parliament agreed to expand the use of biomass for power generation to 1.2 Mt of straw and to 0.2 Mt of wood before the year 2000, which will increase the biomass component by a further 20 PJ.

50. Finland is a leading country in the use of modern bioenergy. The country's primary energy consumption in 1993 was 1,260 PJ, of which more than 19 per cent came from biomass (240 PJ), 14 per cent wood-derived and 5 per cent from peat. The Government's aim is to increase this by 25 per cent by the year 2005.

51. Sweden obtains about 17 per cent of its energy (256 PJ) from biofuels. The use of these fuels can be split into four different sectors: forest products (157 PJ); individual households (40 PJ); district heating (49 PJ), which is growing fast; and electricity generation from combined heat and power (CHP), obtained from various woodfuels (9 PJ). There is much more potential to produce energy from indigenous biomass fuels, particularly from agro-industrial wastes and energy crops grown on marginal and other land. Currently over 14,000 ha of short-rotation willow is being grown under bioenergy schemes. Sweden also imported a small amount of biomass fuels, indicating the potential for the future development of an international trade in biofuels. A recent study of a 205 MW district heating biomass plant in Vaxjo concluded that a combination of monetary and social factors has made Sweden's first biomass plant commercially viable.

52. In the early 1990s renewable energy in the United Kingdom contributed barely 1 per cent of the country's primary energy (a third from biomass and the rest, hydro). However, estimates put the potential contribution to electricity generation at 5-25 per cent in 2005 and 5-63 per cent in 2025. Renewable energy has been given a stimulus by the Non-Fossil Fuel Obligation (NFFO) which empowers the Government to make orders obliging the electric utilities to contract for specified minimum amounts of non-fossil fuel sources for electricity generation. The aim is to achieve 1,500 MW of electricity from renewable sources by the year 2000; so far 900 MW has been awarded. This has been achieved with relatively few public subsidies, compared to nuclear energy and coal, thanks to a competitive bidding process. Combined heat and power biomass projects have recently been included within NFFO.

53. The United States currently obtains 4 per cent of its energy from biomass, and at a recent peak about 9,000 MW of biomass-fired electric power was installed. A combination of factors (low oil prices, intensified competition in the utility sector, shutdown of old, less efficient plants, and lower energy demand) have resulted in a reduction of this capacity to over 7,000 MW. The Department of Energy, in partnership with the private sector, is increasing efforts to double biomass conversion efficiencies and reduce biomass power costs. It is estimated that by 2010, over 13,000 MW of biomass power generation could be installed, supporting over 170,000 jobs. Other projections indicate as much as 22,000 MW and 50,000 MW of biomass electric capacity, and about 283,000 jobs by the year 2010.

3. Briquetting

54. Briquetting is making a comeback in a number of countries due to various factors - the existence of readily available residues, convenience, advances in densification technology, attractive cost, and entrepreneurial opportunities. In Sao Paulo state, Brazil, some 30,000 t are consumed monthly - 20,000 by the commercial sector, such as bakeries and pizzerias, and 10,000 by the industrial sector. Briquettes are produced from sawdust and other processed residues. The main reasons given for using briquettes include convenience, homogeneity and high energy content, and price. India has also good possibilities: 260 Mt/yr of agricultural residues, of which about 100 Mt/yr are wasted, could be used for making briquettes.

4. Liquid fuels

55. Global interest in liquid biofuels for transportation has increased considerably over the past decade, despite low oil prices, and there are detailed studies available on costs and environmental factors. A European Community committee proposed as a target that up to 5 per cent of the liquid fuel market could be supplied by bioethanol and biodiesel by 2010 and that an agricultural area of 7 Mha (5.5 per cent of the utilized agricultural area of the European Community) would be necessary to produce 7 Mtoe. The world's major producers of liquid biofuels are Brazil and the United States, followed by the European Community. Other countries can be considered small producers by comparison.

56. Biodiesel comprises ethyl or methyl esters of edible oils. Rape methyl ester (RME), produced from oilseed rape, is the main source in Europe and Canada, while soya oil is used in the United States. The CO_2 benefits of biodiesel depend on the inputs used and the use of by-products, and are therefore variable. Other environmental benefits include negligible sulphur, reduced particulates, and a product that biodegrades within a few days (making it particularly suitable for use on inland waterways and in other fragile environments). Furthermore, rapeseed-based biodiesel has superior lubrication properties. Biodiesel is also produced in various developing countries, such as Brazil, Mali and Thailand. In Mali a project is under way to determine the potential of producing vegetable oil from Jatropha curcas as a diesel substitute, and other applications show encouraging results.

57. Bioethanol is produced from crops with high sugar or starch content. Alcohols have favourable combustion characteristics - clean burning and high octane-rated performance. Furthermore, there are numerous environmental advantages, particularly with regard to lead, CO_2, SO_2, particulates, hydrocarbons, and CO emissions. Brazil and the United States have pioneered ethanol fuel programmes on a large scale; on a smaller scale, so have Zimbabwe, Kenya and Malawi. Some countries have modernized their sugar industries and are able to produce sugar, alcohol and electricity with low production costs. In the European Community trials of bioethanol have been carried out in Germany, Italy and Sweden, and a small amount is already blended with gasoline in France. The most promising feedstocks include cereals, sugarbeets, sweet sorghum, Jerusalem artichokes, and grapes.

58. Brazil is a major user of biomass, particularly in modern industrial applications. Since the ProAlcool Programme was set up in 1975, about 180 billion litres of bioethanol have been produced, currently replacing about 200,000 barrels/day of imported oil. At its peak (late 1980s) almost 5 million automobiles ran on pure bioethanol, and a further 9 million ran on a 20-22 per cent blend of alcohol and gasoline. Late in the 1980s the combination of high demand for ethanol, higher prices for sugar and uncertain governmental policy resulted in a shortage of ethanol, and the percentage of new neat ethanol cars dropped to 51 in 1989 and to less than 20 in 1994. Since 1976 some 119 billion litres of gasoline have been replaced by ethanol with a total value of $27 billion (1994$). This compares with $11.3 billion total investment in the ProAlcool Programme. The Government established several support mechanisms: ensuring a market, guaranteeing a price, providing financial incentives to ethanol producers and car owners, and investments in research and development. About 700,000 direct jobs with perhaps 3-4 times that number of indirect jobs have been created. However, ProAlcool has had certain economic difficulties, mainly owing to the changes in the oil and sugarcane markets, which will have to be overcome. The industry's future cannot be as secure without a stabilized supply and demand of alcohol.

59. The United States is the world's second fuel ethanol producer. In 1994 production was about 5.3 billion litres (1.4 billion United States gallons), and a further 908 million litres (240 million gallons) of new capacity is under construction. Further expansion is planned, since ethanol is expected to enter into the ether market in the form of ETBE and as "neat" fuel. Ethanol is now produced in 21 states, represents 10 per cent of the country's fuel sales, and is used by over 100 million motorists. Ethanol is produced from grain, cheese whey, citrus wastes, and forestry residues, but the predominant source is corn (maize). Provisions of the Clean Air Act of 1990 and the National Energy Policy Act of 1992 have created new market opportunities for ethanol, methanol and natural gas, by phasing in requirements for fleet vehicles to operate on cleaner fuels. The General Electric Company estimates that by 2005, some 5 million vehicles will be running on non-petroleum fuels.

60. In Zimbabwe, annual production of about 40M litres of ethanol has been possible since 1983, except during the severe 1991/92 drought. The ethanol plant at Triangle has operated successfully for almost 15 years, financed mainly by local capital, with home-based technology required whenever possible rather than oversophisticated equipment from abroad. The capital cost was only $6.4 million (1980 prices), the lowest capital cost per litre for any ethanol plant in the world. Triangle offers an example of good use of relatively simple technology, local infrastructure, and political commitment.

61. Until recently, methanol fuel or biomass-derived methanol was not seen as a promising alternative to fossil fuels due to the high cost of biomass feedstock and economics of scale. However, important technical advances of recent years are changing this view. Biomass-derived methanol can make major contributions to energy requirements for road transportation if used in fuel cell vehicles (FCV). Such systems offer attractive economics in the year 2010 time-frame and the potential for both very low emissions of local air pollutants and low net CO_2 emissions if the biomass is grown sustainably.

5. Biogas

62. Biogas is produced by the anaerobic fermentation of organic material. Production systems are relatively simple and can operate at small and large scales practically anywhere, with the gas being as versatile as natural gas. Anaerobic digestion can make a significant contribution to disposal of domestic, industrial and agricultural wastes. The economics of biogas production have received considerable attention, particularly in industrial countries where energy production is combined with waste treatment, air pollution abatement and meeting environmental legislation.

63. In China, at the end of 1993, about five and a quarter million farmer households had biogas digesters, with an annual production of approximately 1.2 billion m^3. In addition, China has over 600 large and medium-sized biogas plants that use organic waste from animals and poultry farms, wineries etc., with a combined capacity of 220,000 m^3. They process about 20 million tons of organic waste annually, servicing 84,000 households. China has also built 24,000 biogas purification digesters to treat wastes in urban areas, with a capacity of nearly 1 million m^3, treating waste water for 2 million people. Biogas is also used to generate electricity in China. There are about 190 biogas-based power generation units, with a total installed generation capacity of almost 3,500 kW and an annual generation of 3 GWh of electricity.

64. In India, in 1980, about 80,000 family biogas plants were already in operation, reaching 1.85 million in 1993, of which about two thirds are operational. The number of community biogas plants was 875. The total market potential for family biogas plants has been estimated to be around 12 million units. The main goals of the National Programme on Biogas Development are to provide clean cooking energy; produce enriched manure to supplement chemical fertilizers; improve the quality of life of rural women; and improve sanitation and hygiene.

65. In Denmark, since the mid-1980s, 10 centralized and 10 single-farm biogas plants have been established, with an output of 14 million m^3 per annum (0.5 PJ). The concept of centralized plants has been well developed. The centralized plants co-digest animal manure and vegetable wastes, producing biogas and fertilizer as a result. Their capacities range from 50 to 500 t/feedstock/day, producing between 1,000 and 1,500 m^3 of biogas per day. Most of the biogas is used for CHP generation. The costs of biogas (tax excepted) is DK1.60-1.70/m^3, ($0.15 to $0.16), at October 1994 prices.

V. ECONOMICS AND COSTS OF THE BIOMASS OPTION

66. Most biomass energy technologies have not yet reached a stage where market forces alone can make the adoption of these technologies possible. One of the principal barriers to the commercialization of all renewable energy technologies is that current energy markets mostly ignore the social and environmental costs and risks associated with conventional fuel use. Furthermore, conventional energy sources tend to receive large subsidies and support; for example, it is estimated that the total external costs of energy in the United States are $100-300 billion/yr, and in many developing economies, energy prices are

subsidized by 30-50 per cent. Other external costs of conventional energy which are usually not taken into account include the long-term costs of depletion of finite resources and the costs associated with ensuring supplies from foreign sources.

67. Competition in the world's energy markets does not take place on a "level playing field". Existing infrastructure, tax regimes, finance for research and development, and the power of political interest groups all tend to work in favour of fossil fuels and nuclear energy, at the expense of renewables such as biomass. Thus, at present, it is difficult for biomass to be competitive with such fossil fuels, except in certain niche markets or where sufficient tax incentives exist. To improve this situation, attention needs to be focused on two key areas: reducing the cost of producing biomass fuels/feedstocks; and reducing capital investment costs for plant converting biomass to useful energy carriers (such as electricity or liquid fuels).

68. Capital costs for biomass energy facilities tend to be high because of their novelty (except for ethanol) and relatively small scale. These factors raise prices compared to fossil-fuelled plants, where economies of scale and experience are exploited. This underlines the need for demonstration plants for newer and more promising technologies, and their replication and progressive improvement. It has been predicted that specific investment costs for a biomass integrated gasifier/gas turbine (BIG/GT) electricity generation plant would fall from $3,000 kW to 1300 kW over the course of 10 replications.

A. Biomass production

69. Agricultural crops for biomass energy, such as maize, sugarcane and rapeseed already achieve high yields as a result of long-standing research and development efforts. Trees and herbaceous energy crops, on the other hand, are under study as energy feedstock but are starting to be the focus of research into high yielding species for energy production. At experimental stations hybrid poplar cultivars in the north-western United States can produce up to 29.6 odt/ha/yr, and switchgrass in the south-eastern United States up to 30.4 odt/ha/yr.

70. As a yardstick, internationally traded coal at present costs approximately $1.8/GJ ($45/t). By 2010 the United States Department of Energy predicts this will fall to $1.3/GJ for coal supplied to electricity utilities. In order for a large market to develop, a reliable supply of biomass at $2/GJ or less is needed. This corresponds to approximately $40/odt. In Brazil the lower costs and better growing conditions allow plantation biomass to be produced more cheaply. It is estimated that 13 EJ/yr of biomass could be delivered from plantations in north-east Brazil, at $1.5/GJ or less (1988 US$).

71. Other sources of biomass include industrial residues (e.g., pulp and paper waste), forestry residues, and agricultural residues (e.g., straw). These sources can be very cheap or even free of cost, depending on the competing demands and ease of transport. Generally the costs of agriculture are higher in Europe than in the United States; the same applies for biomass energy

production. Current costs tend to be in the range $4-$6/GJ, compared to $2.5-$4/GJ in the United States.

72. The cheapest form of biomass is industrial residues. Agricultural residues such as straw are currently cheaper than plantation wood but could be undercut in future by short rotation coppicing. In Denmark, biofuels are competitive for district heating because of heavy taxation on fossil fuels. Energy and carbon dioxide taxes raise the price of coal from $3.03 to $8.64/GJ, and natural gas from $3.03 to $10.15/GJ. A study from the Netherlands concluded that it would actually be cheaper to import wood from the Baltic States or developing countries rather than produce it domestically.

73. Prices for plantation wood in Sweden ($2.39-$3.39/GJ) and Finland ($3.1/GJ) can be compared with those from plantations in developing countries such as Brazil ($1.41-$1.50/GJ), India ($1.41-$1.91/GJ), Thailand ($1.69-$1.91/GJ) and the Philippines ($1/GJ). Despite these low plantation costs in developing countries, wood can often be obtained even more cheaply by felling native forests. Charcoal is a valued commodity in Brazil, where it provides 41 per cent of the energy used in the steel industry. Charcoal produced from plantation wood costs $3.03-$3.15/GJ to produce, compared to $1.43/GJ from unauthorized deforestation and $2.05/GJ from authorized deforestation. Further research and development to improve yields and reduce costs for plantation wood is needed in order to discourage further tropical deforestation.

B. Electricity and heat

74. Electricity is an energy carrier of much higher value than solid or liquid fuels. Electricity wholesale prices are typically 5¢/kWh ($14/GJ) compared to liquid fuels at $4-5/GJ. Thus, for a relatively high-cost feedstock such as biomass, conversion to electricity could be economically attractive. However, biomass is still in direct competition with fossil fuels, specifically coal, for electricity generation. BIG-GT could benefit from lower specific capital costs than clean coal technology, since it does not require flue gas desulphurization, and lower temperatures are required for wood to gasify, compared to coal. A number of authors are predicting electricity generation costs of approximately 5¢/kWh ($14/GJ) in the near future for industrialized countries and for the present day in Brazil.

75. The sale of heat in combined heat and power (CHP) facilities could generate revenue which would reduce the net cost of electricity production from biomass. The sale of heat will be an important way to improve the competitivity of biomass, given the economies of scale enjoyed by large fossil-fuelled plants. In a United Kingdom study, a lower selling price is assumed for heat: of 1.56¢/kWh. It concludes that the net cost of electricity from wood residues would be 7.6¢/kWh, and from short rotation coppicing plantations, 14.4¢/kWh.

76. Biomass costs 30-40 per cent more than fossil fuels. This is confirmed by operating experience in Austria, where wet bark (a by-product from saw mills) is available for $2.8-8.3/GJ, and is used for district heating. Heat is sold for 6-9¢/kWh. Biomass for district heating is about 30 per cent more expensive than fuel oil in Austria. A recurring problem in the promotion of biomass for energy

is that potential suppliers are discouraged by the lack of market, and potential users are discouraged by the lack of reliable supply. In France grants are awarded for capital investment in biomass district heating, but only once a critical number of installations are planned in one location. This policy is aimed at creating a secure market for biomass producers and manufacturers of conversion technologies. Co-firing biomass with fossil fuels in conventional power stations could also provide a stable market for biomass producers. Interest from the power industry has grown, because co-firing could be a low-cost approach to meeting sulphur emissions standards. Co-firing organic residues could be the most economically attractive biomass to energy conversion available with current technology.

C. Liquid and gaseous fuels

77. Table 2 compares three types of biogas production in Europe. The first example is primarily a system for dealing with the organic fraction of municipal waste, or organic wastes from food processing. Income would be largely from disposal fees rather than the sale of biogas. However, the high biogas yield of such waste makes it a valuable feedstock addition to livestock slurry in the Danish biogas programme, where the increase in yield improves the economic performance overall. The Danish Energy Agency is aiming to reduce operating costs to \$3.75/m^3 of feedstock. Revenue from gas sales (for district heating or CHP) is estimated at \$6.68/m^3 of feedstock. Capital investment grants of approximately 20 per cent are still considered necessary. The third example, small-scale on-farm anaerobic digestion, can be economically viable. However, the small engines suitable for on-farm electricity generation have been very inefficient, though more efficient dual-fuel diesel engines are available. An electricity selling price of 10-15¢/kWh is necessary if farmers and investors in Europe are to become seriously interested in biogas for electricity. For the United Kingdom, using farm biogas for CHP, with heat sold for 1.56¢/kWh, gives a net electricity cost of 9.1¢/kWh.

78. Table 3 presents data for a case study of a community biogas-for-electricity facility in a village in South India. The feedstock is cattle manure. The conclusion of the study was that at higher rates of interest (above 7.5 per cent) and capacity utilization (hours per day), the facility could produce electricity more cheaply than the centralized electricity grid.

79. In industrialized countries experiencing food surpluses, farmers are keen to diversify into these crops, to make use of idle land, machinery and labour. However, with current low oil prices these costs are typically 2-3 times the cost of the competing fossil fuel (the gasoline wholesale price is \$4-5/GJ, and the retail price in the United States is approximately \$7.5/GJ. The lowest costs are in Brazil where sugarcane production costs are low, and capital costs have fallen with experience. Production costs fell by 4 per cent per year from 1979 to 1988, and a further 23 per cent reduction would be possible with relatively little investment. Revenue from the sale of electricity generated from cane bagasse (using BIG/GT technology) could make ethanol competitive in Brazil, even at today’s low oil prices. In industrialized countries efforts have been made to find cheap feedstocks.

80. Woody biomass could provide the cheap feedstock needed to make liquid fuels from biomass more competitive. It has been calculated that ethanol from woody biomass would at present cost $15.1/GJ to produce. Costs as low as $8.6/GJ are possible in the future. By comparison, the wholesale price of gasoline is projected to rise from $4.5/GJ (1993 average) to $6.8/GJ in 2010. Methanol has generated interest as a possible fuel for fuel-cell vehicles. Methanol is normally produced from natural gas or coal. It has been calculated that biomass feedstock prices would have to fall to $1.5/GJ for it to compete with coal. For comparison, estimates of production costs for methanol from natural gas and coal are $7.3/GJ and $11.7/GJ, respectively. Table 4 represents production cost and selling prices for biodiesel. Diesel is the competing fossil fuel and has wholesale prices of approximately $5.5/GJ. Valuable co-products (animal feed and glycerol) can reduce the net cost of production. If taxed at 10 per cent of the rate levied on diesel, biodiesel could develop a market share in Europe. Niche markets could exist where air and water quality is particularly important, such as national parks, waterways and ski areas.

Table 2. Biogas plant yields, costs and revenues from sale of energy in Europe

Type of plant	Gas yield (m^3 per m^3 of feedstock)	Value of gas (US$/$m^3$ of feedstock) a/	Capital and operating cost (US$/$m^3$ of feedstock)	Net value of energy (US$/$m^3$ of feedstock)
Specialized plant for municipal solid wastes b/	60-150	7-18	80-150	< -60 c/
Danish centralized biogas programme	20-80	2-10	7-14	-12 - +3
Low cost on-farm (Switzerland, Germany)	5-20	1-2	1-5	-4 - +1

Source: Department for Policy Coordination and Sustainable Development of the United Nations Secretariat.

a/ Biogas selling price was $0.12 per m^3 of gas.

b/ Source-sorted municipal solid waste or vegetable/garden/fruit waste.

c/ Disposal fees would be the main source of revenue for this type of plant.

Table 3. Costs for a small community biogas-based electricity system in Pura, India

Cost per kWh installed capacity (1992)	US$ 1,104.00
Cost of electricity if generating for 4.1 hours per day	25 US cents/kWh
Cost of electricity if generating for 20 hours per day	7 US cents/kWh
Minimum interest rate at which biogas electricity is cheaper than a centralized electricity system	7.5%

Source: Department for Policy Coordination and Sustainable Development of the United Nations Secretariat.

Table 4. Biodiesel costs in Europe and the United States of America

Year	Location	Feedstock	Cost (US cents/litre)	Cost (US$/GJ)
1994	United States	Soybean	81.9	22.7 a/
1994	United States	Rapeseed	72.7	19.8 a/
1994	European Community/ United States	Rapeseed	81.7-115.8	24.9-35.3 b/
1995	United Kingdom	Rapeseed	51.3	15.6 c/
1995	United Kingdom	Rapeseed	79.1	24.1 d/
1995	European Community	Rapeseed	57.0	17.7
2005	European Community	Rapeseed	42.0	12.8
Future	European Community/ United States	Rapeseed	41.0-50.3	12.5-15.3 b/

Source: Department for Policy Coordination and Sustainable Development of the United Nations Secretariat.

a/ Price for food-grade oil from plants in Montana and Missouri.

b/ 1994 price is a production cost using a 5 per cent discount rate and factor costs for feedstock (i.e., market price plus average subsidy to farmers). "Future" cost uses lowest 1991 price or world market price, and 5 per cent discount rate.

c/ Production cost of 85.1 US cents per litre minus co-product revenue of 34.8 US cents per litre - assumes capital cost repaid over five years at 10 per cent interest.

d/ Selling price, assuming biodiesel is taxed at 10 per cent of the rate of taxation on mineral diesel (selling price 85.1 US cents per litre).

D. Comparison of biomass costs under a single methodology

81. Comparisons of forms of biomass energy are made difficult by the different assumptions made by authors in their calculations. In a model for biomass energy costs in Australia, which takes account of available resources, market opportunities and environmental impact, the seven most promising systems are (not in order of priority):

(a) Woody residues to electricity;

(b) Municipal solid wastes to electricity;

(c) Animal/human wastes to electricity;

(d) Woody biomass to ethanol;

(e) Woody biomass to methanol;

(f) Oilseeds to oilseed esters (biodiesel);

(g) Biomass to oxygenates.

E. External costs

82. Environmental and social costs are hard to estimate since it is difficult to assign a fixed value to human life and environmental amenities. It is easier to estimate medical costs or clean-up costs - for example, the Exxon Valdez oil spill cost $2.2 billion, the Three Mile Island nuclear accident cost $1 billion. Estimated external environmental effects of electricity production (1982) in Germany have been estimated to be DM 0.011-0.061/kWh for fossil fuels and DM 0.012-0.120/kWh for nuclear power. When other external costs and support are included, the total cost (1982) comes to DM 0.039-0.088/kWh for fossil fuels and DM 0.097-0.208/kWh for nuclear.

83. Therefore, renewable energy sources, which produce few or no external costs and have several positive external effects, are systematically put at a disadvantage. Internalizing external costs and benefits and reallocating subsidies in a more equitable manner must become a priority if renewables are to be compared impartially ("level playing field") with fossil fuels. Some Governments are trying to develop programmes to account for external costs such as taxes on emissions and incentives for cleaner fuels, but few schemes have yet been put into practice and most have met with strong opposition. In general, current emission regulations and charges bear little relation to the real damage imposed by fossil fuels and the waste disposal, insurance, and decommissioning costs of nuclear plants, since they tend to be political compromises.

84. The cost estimates above take account of private (internal) costs only. All economic activity, and particularly energy production, also leads to external costs, which accrue to third parties other than the buyer and seller. These can be environmental (e.g., pollution damage to crops) or non-environmental (e.g., direct subsidies, national security of energy supply,

research and development costs, goods and services publicly supplied). Calculation of money values of externalities is controversial. However, if a common methodology is applied to all fuel types, useful comparisons can be made, and there is some agreement on values between authors. In a study on the external costs of renewables compared to coal for electricity generation in Scotland, wind and hydro had lower external costs than biomass, but landfill gas and MSW combustion had higher external costs. Coal is estimated to have an external cost of 3.55-5.4¢/kWh, compared to energy crops at 0.44-0.59¢/kWh. Consideration of these external costs in planning investment in new generation capacity would thus reduce the cost of biomass relative to coal by 3.1-4.8¢/kWh. Thus biomass for electricity at 7-10¢/kWh would be competitive with the present electricity price of 4-5¢/kWh.

85. The approach taken to valuation of external costs by public utilities in the United States has been examined. In total, 29 States take externalities into consideration in resource planning and/or acquisition. Of those, 22 do so only in a qualitative manner. Only five states attempt to monetize the external costs: California, Massachusetts, Nevada, New York and Wisconsin. The focus has been almost exclusively on environmental externalities (not economic or social), particularly air emissions. There is wide variation in the valuation of externalities between states, since the values adopted for carbon dioxide emissions range from $1.21/t in New York to $25.24/t in Massachusetts. Of the five states, only Massachusetts recognizes that CO_2 emissions from biomass are offset by sequestration during growth. In Massachusetts this reduces the external cost for a wood project from over 5¢/kWh to about 1¢/kWh.

F. Summary

86. The most economically attractive forms of biomass energy are based on organic residues from agriculture, forestry or industry. Where these residues are locally available, co-firing, CHP and district heating are already attractive. As plantation wood costs are reduced, and capital costs fall, biomass to electricity will become increasingly competitive. Advanced gasification technologies for wood to electricity have certain cost advantages over fossil fuelled plants, making them particularly promising. Technology for converting woody biomass to ethanol is commercially unproven and would require a significant oil price rise to become competitive. Where valuable co-products result, as in the case of rapeseed for biodiesel, economic performance is improved. Biogas itself is a by-product of treating organic wastes, and the sale of energy can generate significant revenue. In remote locations local production of biofuels is often less costly than delivering fossil fuels or grid electricity. Consideration of the relative external costs attached to biomass energy compared to fossil fuels would significantly improve the economic viability of biomass. Liquid and gaseous fuels are generally less competitive. However, experience in Brazil has shown that sugarcane for ethanol is approaching economic viability.

VI. POLICY REQUIREMENTS AND IMPLICATIONS

87. The aim of any modern biomass energy system must be:

(a) To maximize yields on a sustainable basis with minimum inputs;

(b) To optimize economic and social benefits to the local and wider communities;

(c) The utilization and selection of appropriate plant material and processes;

(d) Optimum use of land, water, and fertilizer;

(e) To create an adequate infrastructure and strong research and development base;

(f) To internalize externalities. Much of this is still lacking, particularly under the conditions in many developing countries.

88. Although it is expected that market forces will be determining factors in the future development of bioenergy, past experience indicates that given the low price of conventional fuels, hidden subsidies, and institutional barriers, political and fiscal support are necessary if bioenergy is to succeed. A number of countries have provided such support. Austria provided political encouragement through favourable legislation, capital grants, cheaper finance, and education. In Denmark, there has been political support at the highest level for green energy and sustainable development, and Finland allocated substantial funds to research, development and demonstration. In Sweden a catalyst to bioenergy was the decision to phase out nuclear energy. In the United Kingdom the main instrument has been the Non-Fossil Fuel Obligation, through a competitive bidding process. The United States has introduced a number of legislative and economic measures aimed at facilitating the introduction of alternative energies. In developing countries the situation is more difficult. Conventional energy prices (electricity, liquid petroleum gas, kerosene, and diesel) are often kept artificially low through subsidies to facilitate industrialization and for other social reasons, and thus little money is allocated to support bioenergy. Large countries such as Brazil, China and India have alternative energy programmes of some scale. For example, Brazil has been subsidizing ethanol production; China has been supporting biogas and woodstove programmes. In India, the first country to set up a Ministry for renewable energy sources, artificially low-priced energy supplies are hampering the development of bioenergy in most cases.

89. Although subsidies may be politically acceptable for renewable energies until they reach some kind of maturity, ultimately it will be the market forces that play the main role. Thus it is important for all costs and benefits of energy to be internalized. In the present political climate it will not be possible to provide subsidies for long periods, since energy prices are more likely to reflect prevailing international market prices.

A. Fiscal incentives

90. Taxes and other fiscal incentives are well established instruments used to stimulate particular energy sources. Taxes can be both barriers and incentives for promoting new energy sources - e.g., in the United States federal taxes have played both roles, depending very much on the type of tax measure. Carbon taxes are a relatively new concept but can play a crucial role in helping to implement low- or non-CO_2 emitting energy initiatives such as biomass. Carbon taxes are basically a policy instrument and as such will vary from country to country and specific circumstances. The use of taxes was widely advocated in the 1980s as an efficient way of supporting renewable energy and for abatement of greenhouse gases. This advocacy seems to have subsided somewhat, due mainly to industrial hostility and political constraints. Although the cost of taxation may not be necessarily high, the idea of higher taxes, coupled with the global nature of the problem, has played against it. However, the concept is beginning to be applied in some countries: in Sweden carbon tax, introduced in 1991, is roughly equivalent to $150 per tC, affecting oil, coal, natural gas and petroleum; Norway's carbon tax is about $120 per tC.

91. It has been estimated that a 0.2 per cent levy on fossil fuel consumption in the OECD countries would raise some $833 million annually. If half of the levy were spent on buying down the cost of the most promising electricity generation technologies (wind, solar thermal, photovoltaic and biomass energy), they could obtain full commercialization within 10 years or so. An example is the United Kingdom's Non-Fossil Fuel Obligation (NFFO) programme which has stimulated a decrease in the bid price for wind power from 14.4-17.6¢/kWh in 1990 to 6.4¢/kWh in 1994, through a process of learning by doing. For the 70 cheapest NFFO-3 projects, totalling 316 MW, the bid price averaged 6.2¢/kWh, compared to the 4.2¢/kWh average price of electricity based on fossil fuels which excludes environmental and social costs, estimated to be as high as 6.4¢/kWh. The total subsidy for NFFO-3 projects is about $27-35M, or 48-64¢ person/yr over the 20-year contract period, or less than 0.2 per cent of the national consumers' electricity bill.

B. Future energy trends

92. Three main aspects will be examined below: energy in general; bioenergy; and biofuels (liquid and gaseous).

1. Energy

93. All indications point to a more complex and varied future energy supply matrix in which renewable sources of energy will have a major and increasing share of the market. A more decentralized and diversified energy supply system would allow greater control at the national, regional and local levels. Energy efficiency will increase, therefore allowing continued economic growth without necessarily increasing energy consumption per capita in industrial countries. In developing countries, energy demand will continue to grow, due to population growth and better living standards, but at lower pace, due to technological improvements. Fossil fuels will continue to be used on a large scale well into

the next century but with a diminished role on a percentage basis, while alternative energy sources, the so-called "carbon free" energies, will see their market share increase quite considerably. The transition from a predominantly fossil fuel energy system to a more diversified and decentralized one could be accelerated greatly by the increasing power of shared and processed information.

2. Bioenergy

94. It is becoming clear that bioenergy could be a major source of energy in the next century. Modern biomass energy use will increase quite considerably while traditional uses will experience a decline in relative terms. In absolute terms, however, due to population growth, it is likely that the use of traditional biomass will continue to increase. The use of bioenergy on a large industrial scale will require important advances in agro-technologies to increase productivity and reduce costs and in transformation technologies (e.g., gasification). The most promising bioenergy market is for combined heat and power (CHP) and for bioelectricity which can use already established technologies. In the medium term, emerging technologies - e.g., BIG, STIG, BIG/GTs and GTCC - can open new economic opportunities.

3. Biofuels

95. The combination of technological and environmental factors and high fuel efficiency is making possible the introduction of new transportation fuels at a faster rate than thought possible a decade ago, despite low oil prices. This will, however, depend on a mix of political, commercial and technical factors. High quality liquid fuels will be reserved for road and air transportation, and oil will dominate at least until 2050.

96. Liquid biofuels will be dominated by ethanol from sugarcane (Brazil), maize (United States), and a variety of crops in the European Community, the three main production areas. Many sugarcane-producing countries will probably enter the ethanol market but on a smaller scale. Non-transportation uses of ethanol may include the chemical industry and cooking, and water pumping water in rural areas. In the longer term the production of ethanol by enzymatic hydrolysis from ligno-cellulosic feedstocks could increase the market very considerably since it may be possible to produce ethanol at competitive prices.

97. Methanol and hydrogen could play a role around the year 2010 when used in fuel cell vehicles (FCV). Initially, methanol and hydrogen would be produced by steam-reforming natural gas, which is the more economic route in the short term. Although much needs to be done, methanol and hydrogen from biomass could potentially make a major contribution to transport fuel requirements on a competitive basis and bring many economic benefits, particularly when produced in rural areas of developing countries.

98. There has been an increasing interest on biodiesel, but excluding a few countries such as Brazil, the European Community and possibly the United States, the market will be small and localized because of high costs and the high demand for edible oils. In remoter rural areas of some developing countries where

there is a high production potential, biodiesel could play a role in meeting local needs. For example, in Brazil, with some 40,000 small isolated rural villages, it makes sense to produce biodiesel to meet local needs (lighting, pumping water etc.). The higher cost may be justified on the grounds of high connection cost to the national grid and transportation cost of diesel. In the short term, biodiesel will probably be confined to OECD countries that, for environmental, agricultural and other reasons, can afford to pay high subsidies.

C. Major research gaps

99. Despite the overwhelming importance of biomass energy in many developing countries, planning for the management of production, distribution, and use of biomass receives inadequate attention among policy makers and energy planners. The few relevant policy provisions that may exist are often ineffectively put into practice due to a combination of factors such as budgetary constraints, lack of manpower, low priority, lack of data etc. Considerably more data on all aspects of biomass production and use are required on an ongoing basis, especially if biomass energy is to be placed on an equal research basis as other energies. Lack of data hampers energy planning for the production and use of biomass energy. Few detailed studies exist, at national or regional levels. For example, there are few biomass energy flows at the national level except in the United States, Kenya and Zimbabwe, and very few reliable data are available for their compilation. Yet biomass energy flows are very useful methods of representing data and can provide a good overview of national, regional, and local conditions and opportunities for energy provision and saving.

100. Research on biomass energy has usually been focused on supply and consumption data and conversion processes, and insufficient attention and resources have been allocated to more basic research on production, harvesting, and integrated conversion processes. Additionally, little research is done to study market flows, economics and the role of entrepreneurs in making bioenergies available to end uses and whether those services are provided in a sustainable manner.

VII. CONCLUSIONS

101. The growing interest in bioenergy covers a broad range of issues - greater environmental, ecological and sustainability concerns; the potential biomass energy contribution, in both modern and traditional forms; the versatility and global availability of bioenergy; local benefits; the notion in the industrial countries of growing energy crops on set-aside land; and technological advances that improve economic viability. For the first time bioenergy is being recognized as a significant component in many future energy scenarios, ranging from about 10 per cent to over 30 per cent of energy supply by around the year 2050. The Renewable Intensive Global Energy Scenario, for example, forecasts that by 2050, 17 per cent of the world’s electricity could be generated from modern biomass. Given the nature of bioenergy, so inadequately stated and undervalued in many official statistics, it is not possible to present a more reasonably accurate picture. For so long the main source of energy in many poor countries and an important component in many industrial countries, the future

role of biomass as a modern energy source could be prominent. However, in its traditional forms, its contribution may be relatively less important (but not in absolute terms).

102. A major problem with traditional forms of bioenergy is that they are often used inefficiently and too little useful energy is produced. Far more energy can be economically produced from biomass than is done at present, so that the biomass energy potential could be considerably increased. Indeed low energy efficiencies, particularly in rural areas of developing countries, have not been adequately addressed nor have they been a priority. When bioenergy is inefficiently used, it can be environmentally detrimental. However, if produced efficiently and on a sustainable manner, bioenergy has many environmental and social benefits compared to fossil fuels. These benefits range from socio-economic development, waste control and disposal and nutrient recycling, to job creation, CO_2 mitigation, and improved land management, depending on the nature and technology in question. Of the various strategies under consideration to mitigate GHG production, the substitution of fossil fuels by biomass is an option that is gaining acceptance, since it appears to be an effective strategy, both economically and environmentally (in particular, for offsetting CO_2: the potential for CO_2 abatement ranges from 1 Gt to 3.5 Gt per annum).

103. A major, and perhaps misconceived concern, is the long-term environmental and ecological impact of large monoculture energy plantations. Recent experience and research indicates that with careful management practices, land use planning, and appropriate selection of species and clones, most of the negative effects can be avoided and positive attributes can be emphasized.

104. Land availability and bioenergy production are intrinsically intertwined. Many studies have been carried out to determine how much land is available globally for non-agricultural purposes. The amounts range from 150 Mha to 1,200 Mha, reflecting lack of adequate criteria for classifying degraded and abandoned lands. What these and other studies seem to demonstrate is that the perceived constraints on land are not well founded, notwithstanding local priorities of land use. What is not questioned is that considerable amounts of land in the European Community and the United States are being taken out of production, while in tropical developing countries, large areas of deforested and degraded land, unsuitable for agricultural purposes, could be enhanced in value by the establishment of bioenergy plantations.

105. Competition between bioenergy with food production is another voiced concern. Some of the issues which need to be scrutinized before a proper analysis of the "food versus fuel" problem can be undertaken are: food production and consumption, distribution patterns, hunger, lack of purchasing power, inequality, land and grains used for livestock, underutilization of agricultural land, inappropriate investments, export of crops, land tenure, wars, and political interference.

106. With proper support (research and development, infrastructure, finance etc.) farmers have demonstrated that they can produce far more food. If more food is to be made available to those who currently haven’t enough, changes need to be made in the present food production and distribution system. It is also

important to remember that food and energy are mutually interrelated and complementary. Bioenergy programmes, coupled with agroforestry and integrated farming, can improve food production by making energy and income available where they are needed.

107. Of the many social benefits of bioenergy, job creation has been heralded as one of the most important. Traditional bioenergy is labour-intensive and employs large numbers of people, often unrecorded - e.g., charcoal production in sub-Saharan Africa is a major energy and economic activity, worth about $2 billion and employing hundreds of thousands of people, yet it goes largely unnoticed by Governments and aid agencies. Modern bioenergy production is less employment-intensive but generates more jobs than similar industrial activities.

108. A range of technological advances are opening up new opportunities for bioenergy, considered only a few years ago as long-term prospects. Notable advances have been made in gasification and other technologies being spearheaded by the European Community and the United States: BIG, GTCC, co-firing, biocrude etc., with Brazil and India also becoming important players. In biofuels, Brazil and the United States dominate the ethanol market; in biogas, Denmark, China and India. Methanol and hydrogen from biomass and their potential for use in fuel cell vehicles are promising. Most biomass energy technologies have not yet reached a stage where market forces alone can make their adoption possible. Some exceptions are the use of residues from agriculture and forestry when they are readily available, for generating heat, electricity, and biogas which can be sold at competitive prices. One of the principal barriers to the commercialization of all renewable energy technologies is that current energy markets mostly ignore the social and environmental costs and risks associated with conventional fuel use, the hidden subsidies, the long-term costs of depletion of finite resources, and the costs associated with securing reliable supplies from foreign sources.

109. Growing environmental and ecological pressures, combined with technological advances and increases in efficiency and productivity, are making biomass feedstocks economically attractive in many parts of the world. The most immediate commercial prospects are in cogeneration (heat and electricity), spearheaded by the pulp/paper and timber industries using wood wastes, bagasse from the sugarcane industry, and other agricultural residues for use in agro-industry.

110. For bioenergy to succeed, particularly in its modern forms, it must be put on more equal terms with the long-established fossil fuels, and for that to occur, some initial incentives (in the form of subsidies, financial advantages, carbon taxes etc.) will be necessary. The experience of countries that have a significant modern bioenergy contribution clearly indicates that this is the case. In the longer term, market forces must be allowed to play their role.

111. Predicting energy trends is notoriously difficult. Future energy supplies may be more decentralized, with renewable energies playing an increasing role. Increased energy efficiency, together with technological developments, might curtail increases in energy demand. Fossil fuels will continue to dominate well into the next century, but bioenergy in its various forms will also increase its market share. Oil will still dominate the transportation system, but biomass-

based liquid fuels will increase their share. Biodiesel may also grow in the OECD countries but will remain localized in some developing countries. Methanol and hydrogen from biomass are possible energy sources in the longer term.

112. Major research and development gaps need to be addressed, especially as they relate to sustainable production and use in an environmentally acceptable manner. A major problem with bioenergy is that until recently it has had a low priority in the allocation of resources for research and development, planning and implementation. It will take time to reverse this neglect.

VIII. RECOMMENDATIONS

113. It is neither feasible nor desirable to propose a uniform and universal set of recommendations, given the nature of bioenergy. However, to facilitate the introduction of bioenergy, the following broad guidelines are recommended:

(a) Formulate clear policies to promote bioenergy on an equal footing with conventional energy sources, through rational energy pricing;

(b) Provide financial incentives to bioenergy, in particular to utilities and local entrepreneurs, and allow the sale of bioelectricity, heat and gases by private generators; provide capital and credit to encourage commercial activities;

(c) Directed research and development to the most promising areas of biomass so as to increase energy supply and improve the technological base;

(d) Examine closely past successes and failures so as to assist policy makers with well informed recommendations, especially with regard to environmental acceptability and sustainability at the local and regional levels;

(e) Internalize all external costs and benefits of bioenergy; develop methodologies for doing so;

(f) Develop bioenergy distribution systems that facilitate consumption and use;

(g) Consider interrelated socio-economic aspects of bioenergy;

(h) Pay more attention to sustainable production and use of biomass energy feedstocks, methodologies of conversion, and efficient energy flows;

(i) Allocate more research and development to pollution abatement (especially at the local level), energy efficiency, and development of newer conversion systems;

(j) Improve capacity-building in bioenergy management skills, taking maximum advantage of existing local knowledge, and encourage multidisciplinary approaches;

(k) Promote the sustainable development of large-scale biomass plantations in order to reduce costs and achieve environmental acceptability;

(l) Improve market opportunities and conditions for potential suppliers and improve supplies for potential markets.

Notes

1/ Official Records of the Economic and Social Council, 1994, Supplement No. 5 (E/1994/25).

2/ Official Records of the Economic and Social Council, 1995, Supplement No. 5 (E/1995/25), chap. I.

3/ D. O. Hall, F. Rosillo-Calle and J. I. Scrase, "Biomass: an environmentally acceptable and sustainable energy source for the future".
