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Biomass Energy as a Source of Renewable Energy

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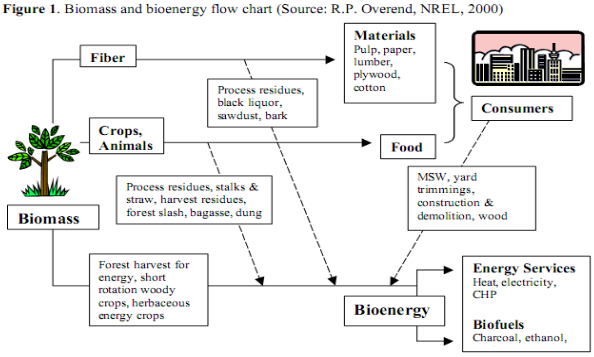
1. BIOMASS ENERGY

1.1 INTRODUCTION

Biomass is the term used for all organic material originating from plants (including algae), trees and crops and is essentially the collection and storage of the sun's energy through photosynthesis. Biomass energy, or bioenergy, is the conversion of biomass into useful forms of energy such as heat, electricity and liquid fuels.

Biomass for bioenergy comes either directly from the land, as dedicated energy crops, or from residues generated in the processing of crops for food or other products such as pulp and paper from the wood industry. Another important contribution is from post-consumer residue streams such as construction and demolition wood, pallets used in transportation, and the clean fraction of municipal solid waste (MSW). The biomass to bioenergy system can be considered as the management of flow of solar generated materials, food, and fiber in our society. These inter-relationships are shown in Figure 1, which presents the various resource types and applications, showing the flow of their harvest and residues to bioenergy applications. Not all biomass is directly used to produce energy but rather it can be converted into intermediate energy carriers called biofuels. This includes charcoal (higher energy density solid fuel), ethanol (liquid fuel), or producer-gas (from gasification of biomass).

Figure 1. Biomass and bioenergy flow chart (Source: R.P. Overend, NREL, 2000)



Biomass was the first energy source harnessed by humans, and for nearly all of human history, wood has been our dominant energy source. Only during the last century, with the development of efficient techniques to extract and burn fossil fuels, have coal, oil, and natural gas, replaced wood as the industrialized world's primary fuel. Today some 40 to 55 exajoules (EJ = 1018 joules) per year of biomass is used for energy, out of about 450 EJ per year of total energy use, or an estimated 10-14 percent, making it the fourth largest source of energy behind oil (33 percent), coal (11 percent), and natural gas (19 percent). The precise amount is uncertain because the majority is used non-commercially in developing countries.

Biomass is usually not considered a modern energy source, given the role that it has played, and continues to play, in most developing countries. In developing countries it still accounts for an estimated one third of primary energy use while in the poorest up to 90% of all energy is supplied by biomass. Over two billion people cook by direct combustion of biomass, and such traditional uses typically involve the inefficient use of biomass fuels, largely from low cost sources such as natural forests, which can further contribute to deforestation and environmental degradation. The direct combustion of biomass fuels, as used in developing countries today for domestic cooking and heating, has been called "the poor man's oil" ranking at the bottom of the ladder of preferred energy carriers where gas and electricity are at the top.

The picture of biomass utilization in developing countries is sharply contrasted by that in industrialized countries. On average, biomass accounts for 3 percent or 4 percent of total energy use in the latter, although where policies supportive of biomass use are in place, e.g. in Austria, Sweden, and Finland, the biomass contribution reaches 11, 18, and 13 percent respectively. Most biomass in industrialized countries is converted into electricity and process heat in cogeneration systems (combined heat and power production) at industrial sites or at municipal district heating facilities. This enables a greater variety of energy services to be derived from the biomass which are much cleaner and use the available biomass resources more efficiently than is typical in developing countries.

Biomass energy has the potential to be "modernized" worldwide, that is produced and converted efficiently and cost-competitively into more convenient forms such as gases, liquids, or electricity. A variety of technologies can convert solid biomass into clean, convenient energy carriers over a range of scales from household/village to large industrial. Some of these technologies are commercially available today while others are still in the development and demonstration stages. If widely implemented, such technologies could enable biomass energy to play a much more significant role in the future than it does today, especially in developing countries.

1.2 THE FUTURE ROLE OF BIOMASS

Modernized biomass energy is projected to play a major role in the future global energy supply. This is being driven not so much by the depletion of fossil fuels, which has ceased to be a defining issue with the discovery of new oil and gas reserves and the large existing coal resources, but rather by the recognized threat of global climate change, caused largely by the burning of fossil fuels. Its carbon neutrality (when produced sustainably) and its relatively even geographical distribution coupled with the expected growth in energy demand in developing countries, where affordable alternatives are not often available, make it a promising energy source in many regions of the world for the 11st century.

Most households in developing countries that use biomass fuels today do so either because it is available at low (or zero) financial cost or because they lack access to or cannot afford higher quality fuels. As incomes rise, preferences tend to shift away from biomass. For example, in the case of cooking, consumer preferences shift with increasing income from dung to crop residues, fuelwood, coal, charcoal, kerosene, liquified petroleum gas, natural gas, and electricity (the well- known household energy ladder). This shift away from biomass energy as incomes rise is associated with the quality of the energy carrier used rather than with the primary energy source itself. If biomass energy is instead modernized, then wider use is conceivable along with benefits such as reduced indoor air pollution. For example, in household cooking gaseous or liquid cooking fuels can be used far more efficiently and conveniently, reaching many more families and emitting far fewer toxic pollutants, than solid fuels.

Estimates of the technical potential of biomass energy are much larger than the present world energy consumption. If agriculture is modernized up to reasonable standards in various regions of the world, several billions of hectares may be available for biomass energy production well into this century. This land would comprise degraded and unproductive lands or excess cropland, and preserve the world's nature areas and quality cropland. Table 1 gives a summary of the potential contribution of biomass to the worlds energy supply according to a number of studies and influential organizations. Although the percentile contribution of biomass varies considerably, depending on the expected future energy demand, the absolute potential contributions of biomass in the long term is high, from about 100 to 300 EJ per year.

Table 1. Role of biomass in future global energy use according to five different studies (Source: Hall, 1998; WEA, 1000)

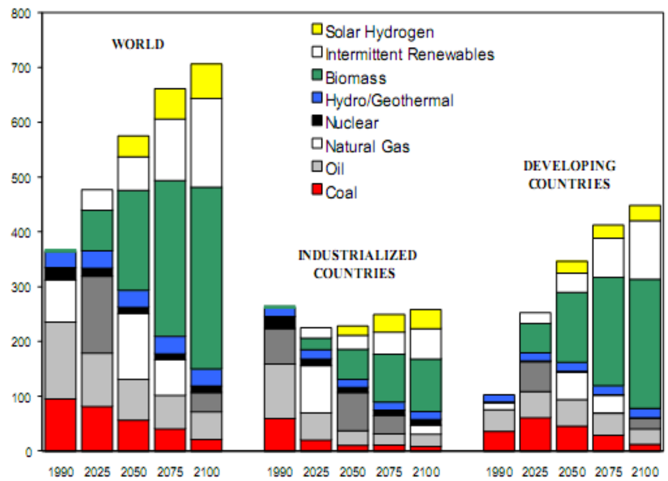
Source	Time frame (Year)	Total projected global energy demand (EJ/year)	Contribution of biomass to energy demand, EJ/year (% of total)	Remarks
IPCC (1996)	1050 1100	560 710	180 (31%) 315 (46 %)	Biomass intensive energy system development
Shell (1994)	1060	1500 900	110 (15%) 100 (11%)	-Sustained growth* -Dematerialization+
WEC (1994)	1050 1100	671-1057 895-1880	94 - 157 (14 -15 %) 131 - 115 (15-11 %)	Range given reflects the outcome of three Scenarios
Greenpeace (1993)	1050 1100	610 986	114 (19 %) 181 (18 %)	Fossil fuels are phased out during the 11st century

* *Business-as-usual scenario*

\+ *Energy conservation scenario*

An Intergovernmental Panel on Climate Change (IPCC) study has explored five energy supply scenarios for satisfying the world's growing demand for energy services in the 11st century while limiting cumulative CO1 emissions between 1990 and 1100 to fewer than 500 gigatonnes of carbon. In all scenarios, a substantial contribution from carbon-neutral biomass energy as a fossil fuel substitute is included to help meet the CO1 emissions targets. When biomass is grown at the same average rate as it is harvested for energy, it is approximately carbon-neutral: carbon dioxide extracted from the atmosphere during growth is released back to the atmosphere during conversion to energy. Figure 1 shows the results for the IPCC's most biomass-intensive scenario where biomass energy contributes 180 EJ/year to global energy supply by 1050 – satisfying about one-third of the total global energy demand, and about half of total energy demand in developing countries. Roughly two-thirds of the global biomass supply in 1050 is assumed to be produced on high-yield energy plantations covering nearly 400 million hectares, or an area equivalent to one-quarter of present planted agricultural area. The other one-third comes from residues produced by agricultural and industrial activities.

Figure 2. Primary commercial energy use by source for the biomass-intensive variant of the IPCC model (IPCC, 1996), shown for the world, for industrialized countries, and for developing countries (Source: Sivan, 1000)



Such large contributions of biomass to the energy supply might help address the global environmental threat of climate change, but it also raises concerns about local and regional environmental and socio-economic impacts. Such issues (discussed in more detail below) include the: depletion of soil nutrients from crop land due to the removal of agricultural residues; leaching of chemicals applied to intensively-cultivated biomass energy crops; loss of biodiversity associated with land conversion to energy crops; diversion to energy uses of biomass resources traditionally used for non-energy purposes, or conversion of land from food to energy production. Bioenergy systems, more so than most other types of energy systems, are inextricably linked to their local environmental and socio-economic contexts.

On the other hand, the large role biomass is expected to play in future energy supplies can be explained by several considerations. Firstly, biomass fuels can substitute more-or-less directly for fossil fuels in the existing energy supply infrastructure. Intermittent renewables such as wind and solar energy are more challenging to the ways we distribute and consume energy. Secondly, the potential resource is large. Thirdly, in developing countries demand for energy is rising rapidly due to population increases, urbanization, and rising living standards. While some fuel switching occurs in the process, the total demand for biomass will also tend to increase, as is currently seen for charcoal. Consequently, there is a growing consensus that energy policies will need to be concerned about the supply and use of biofuels while supporting ways to use these fuels more efficiently and sustainably.

1.3 BIOMASS ENERGY CONVERSION TECHNOLOGIES AND APPLICATIONS

There are a variety of technologies for generating modern energy carriers – electricity, gas, and liquid fuels -- from biomass, which can be used at the household (~10 kW), community (~100 kW), or industrial (~ MW) scale. The different technologies tend to be classed in terms of either the conversion process they use or the end product produced.

1.3.1 COMBUSTION

Direct combustion remains the most common technique for deriving energy from biomass for both heat and electricity production. In colder climates domestic biomass fired heating systems are widespread and recent developments have led to the application of improved heating systems which are automated, have catalytic gas cleaning and make use of standardized fuel (such as pellets). The efficiency benefit compared to open fireplaces is considerable with advanced domestic heaters obtaining efficiencies of over 70 percent with greatly reduced atmospheric emissions. The application of biomass fired district heating is common in the Scandinavian countries, Austria, Germany and various Eastern European countries.

The predominant technology in the world today for electricity generation from biomass, at scales above one megawatt, is the steam-Rankine cycle. This consists of direct combustion of biomass in a boiler to raise steam which is then expanded through a turbine. The steam-Rankine technology is a mature technology introduced into commercial use about 100 years ago. The typical capacity of existing biomass power plants ranges from 1 – 50 MWe with an average around 10 MWe. Energy conversion efficiencies are relatively low, 15 – 15 percent, due to their small size, although technologies and processes to increase these efficiencies are being developed. Steam cycle plants are often located at industrial sites, where the waste heat from the steam turbine is recovered and used for meeting industrial process heat needs. Such combined heat and power (CHP), or cogeneration, systems provide greater levels of energy services per unit of biomass consumed than systems that only generate power and can reach overall efficiencies of greater than 80 percent.

Biomass power generating capacity grew rapidly in the US in the 1980s largely as the result of incentives provided by the Public Utilities Regulatory Policies Act of 1978 (PURPA), which required utilities to purchase electricity from cogenerators and other qualifying independent power producers at a price equal to the utilities' avoided costs. Currently in the U.S. the installed biomass-electric generating capacity is about 7 GW (not including generating capacity of ~ 1.5 GW from MSW and ~ 0.5 GW from landfill gas). The majority of this capacity is located at pulp and paper mills, where biomass fuels are available as byproducts of processing. There are also a substantial number of biomass power plants in California that use agricultural processing wastes as fuel. A significant number of biomass power plants are also found in Scandinavia, especially Sweden, where carbon taxes have encouraged recent expanded use of such systems for combined district heating and power production. By comparison to the steam-Rankine power generating capacity installed in OECD countries, there is relatively little capacity installed in developing countries. The most significant installation of steam-Rankine capacity in developing countries is at factories making sugar and/or ethanol from sugarcane, using bagasse, the fiber residue that remains after juice extraction from sugarcane.

The costs of steam-Rankine systems vary widely depending on the type of turbine, type of boiler, the pressure and temperature of the steam, and other factors. An important characteristic of steam turbines and boilers is that their capital costs (per unit of capacity) are scale-sensitive. This, together with the fact that biomass steam-Rankine systems are constrained to relatively small scales (due to biomass fuel transport cost limitations), typically leads to biomass steam-Rankine systems that are designed to reduce capital costs at the expense of efficiency. For example, biomass-fired systems are typically designed with much more modest steam pressure and temperature than is technologically feasible enabling lower grade steels to be used in boiler tubes. This lowers both the costs and efficiency. Even with such measures to reduce costs, however, capital costs for small-scale systems are still substantial and lead to relatively high electricity generating costs compared to conventional fossil energy power plants. Consequently, existing biomass power plants rely on low, zero, or negative cost biomas, such as primarily residues of agro- and forest product-industry operations. Since there are untapped supplies of low-cost biomass feedstocks available in many regions of the world the economics of steam- Rankine systems are probably reasonable. For example, sugarcane processing industries and sawmills present major opportunities for steam-Rankine based combined heat and power generation from biomass.

An alternative to the above-described direct-fired biomass combustion technologies, and considered the nearest term low-cost option, is biomass co-combustion with fossil fuels in existing boilers. Successful demonstrations using biomass as a supplementary energy source in large high efficiency boilers have been carried out showing that effective biomass fuel substitution can be made in the range of 10–15 percent of the total energy input with minimal plant modifications and no impact on the plant efficiency and operation. This strategy is economical when the biomass fuels are lower cost than the fossil fuels used. For fossil fuel plant capacities greater than 100 MWe, this can mean a substantial amount of biomass and related carbon savings and emissions reductions, particularly for coal substitution.

1.3.2. GASIFICATION

Combustible gas can be produced from biomass through a high temperature thermochemical process. The term gasification commonly refers to this high-temperature thermochemical conversion with the product gas called producer-gas, and involves burning biomass without sufficient air for full combustion, but with enough air to convert the solid biomass into a gaseous fuel. Producer-gas consists primarily of carbon monoxide, hydrogen, carbon dioxide and nitrogen, and has a heating value of 4 to 6 MJ/Nm3, or 10 – 15 percent of the heating value of natural gas. The intended use of the gas and the characteristics of the particular biomass (size, texture, moisture content, etc.) determine the design and operating characteristics of the gasifier and associated equipment. After appropriate treatment, the resulting gases can be burned directly for cooking or heat supply, or can be used in secondary conversion devices such as internal combustion engines or gas turbines for producing electricity or shaft work. The systems used can scale from small to medium (5 –100 kW), suitable for the cooking or lighting needs of a single family or community, up to large grid connected power generation facilities consuming several hundred of kilograms of woody biomass per hour and producing 10-100 MW of electricity.

After the first oil price shock in 1973 crash attempts were made to resurrect and install gasifier/engine systems for electricity generation, especially in remote areas of developing countries. Most of these projects failed, however, because of technical problems arising from the formation of tars and oils (heavy hydrocarbon compounds) during gasification. Condensation of tars on downstream equipment caused system operating problems and failures. Such problems were encountered in many of the gasifier/engine systems installed in the 1970s and 1980s, and led to a second abandonment of gasifier/engine technology by the end of the 1980s. Research efforts continued, however, and have recently led to the identification of gasifier and gas cleanup system designs that largely eliminate tar production and other technical problems, although they tend to still be too expensive. The process of transferring these research findings into commercial products is ongoing, as interest in gasification has again revived with the growing recognition of environmental concerns. One of the main barriers to commercializing biopower technology continues to be the low cost of oil, gas and coal.

One technology that has generated wide interest is the biomass integrated gasification combined cycle (IGCC) technology for larger scale power and combined heat and power (CHP) generation in the range of 5 to 100 MWe. An IGCC system involves sizing and drying of the feedstock, followed by thermochemical gasification to produce a combustible gas, cooling and cleaning of the gas, and combustion in a gas turbine. Steam is raised using the hot exhaust of the gas turbine to drive a steam turbine that generates additional power and/or delivers lower pressure steam for heating purposes. The cascading of a gas turbine and a steam turbine in this manner is commonly called a combined cycle. In approximate terms, the IGCC technology will enable electricity to be made at double or more the efficiency of the steam cycle, and the capital cost per installed kW for commercially mature IGCC units are expected to be lower than for comparably-sized steam cycles. Thus, the overall economics of biomass-based power generation are expected to be considerably better with an IGCC system than with a steam-Rankine system, especially in situations where biomass fuel is relatively expensive.

IGCC technology is expected to be commercially available within a few years, based on current demonstration and commercialization efforts worldwide. Several of the most advanced demonstration projects are in Sweden, the UK, Italy, and Brazil. In Varnamo, Sweden, the first complete biomass fueled IGCC system has been operating for over 1500 hours on forest residues, generating 6 MW of electricity and 9 MW of heat for the local district heating system.

Unfortunately, it was recently shut down probably due its inability to compete economically with fossil fuel systems. In Yorkshire, England, construction of the ARBRE project, an IGCC facility that will generate about 10 MW of electricity from short-rotation biomass plantations, is nearly complete. It is supported under both THERMIE and the U.K.'s Non-Fossil Fuel Obligation-3. The Bioelectrical Project near Pisa, Italy, an IGCC, is also under construction and will use Poplar and Robina wood chips, olive residues, grape residues, and sawdust to produce 11 MWe. At a site in Bahia, Brazil, construction is planned to begin in 1000 on a GEF-World Bank supported demonstration project of a 31 MW IGCC power plant using plantation-grown eucalyptus for fuel. The facility will also test the use of sugarcane bagasse. It has been estimated that if IGCC technology was applied worldwide around 15 % of all current electricity generation from sugarcane producing countries could be produced just from their available sugarcane bagasse resource.

At the intermediate scale producer-gas from biomass gasification can be used in modified internal combustion engines (typically diesel engines), where it can replace 70-80 percent of the conventional fuel required by the engine. These smaller scale biomass gasifiers, coupled to diesel/gas internal combustion engines, operate in the 100-100 kWe range with efficiencies on the order of 15 – 15 percent, and have been made available commercially. They have, however, had only limited operation success due to, gas cleaning, relatively high costs and the required careful operation, which has so far blocked application in large numbers. Thus, practical operation has often been limited to direct heating applications and not electricity where gas cleanup and its associated problems become an issue.

Generally, these smaller gasification/engine systems are targeted toward isolated areas where grid-connections are either unavailable or unreliable and so they can be cost competitive in generating electricity. Some systems have been applied relatively successfully in rural India and some other countries. Efforts to make these systems more workable are underway. In particular, the U.S. National Renewable Energy Laboratory is funding a small modular biopower project to develop biomass systems that are fuel flexible, efficient, simple to operate, have minimum negative impacts on the environment, and provide power in the 5 kW - 5 MW range. This is a three-phase project (feasibility studies, prototype testing, integrated systems demonstration) currently beginning its second phase. There is particularly strong interest in the quality-of-life improvements that can be derived from implementing such gasifier/engine technology for electricity generation at the village-scale in developing countries.

The greatest technical challenge for electricity generating gasifier systems, at all scales, continues to be adequately cleaning the tars and oils from the producer-gas such that the system operates efficiently, is economical, and has minimal toxic byproducts and air emissions.

1.3.3 ANAEROBIC DIGESTION

Combustible gas can also be produced from biomass through the low temperature biological processes called anaerobic (without air) digestion. Biogas is the common name for the gas produced either in specifically designed anaerobic digesters or in landfills by capturing the naturally produced methane. Biogas is typically about 60 percent methane and 40 percent carbon dioxide with a heating value of about 55 percent that of natural gas. Almost any biomass except lignin (a major component of wood) can be converted to biogas -- animal and human wastes, sewage sludge, crop residues, carbon-laden industrial processing byproducts, and landfill material have all been widely used.

Anaerobic digesters generally consist of an inlet, where the organic residues and other wastes are fed into the digester tank; a tank, in which the biomass is typically heated to increase its decomposition rate and partially convert by bacteria into biogas; and an outlet where the biomass of the bacteria that carried out the process and non-digested material remains as sludge and can be removed. The biogas produced can be burned to provide energy for cooking and space heating or to generate electricity. Digestion has a low overall electrical efficiency (roughly 10-15 percent, strongly dependent on the feedstock) and is particularly suited for wet biomass materials. Direct non-energy benefits are especially significant in this process. The effluent sludge from the digester is a concentrated nitrogen fertilizer and the pathogens in the waste are reduced or eliminated by the warm temperatures in the digester tank.

Anaerobic digestion of biomass has been demonstrated and applied commercially with success in a multitude of situations and countries. In India biogas production from manure and wastes is applied widely in many villages and is used for cooking and power generation. Small-scale digesters have been used most extensively in India and China. Over 1.85 million cattle-dung digesters were installed in India by the mid-1990s, but about one-third of these are not operating for a variety of reasons, primarily insufficient dung supply and difficulties with the organization of dung deliveries. A mass popularization effort in China in the 1970s led to some 7 million household-scale digesters being installed, using pig manure and human waste as feed material. Many failed to work, however, due to insufficient or improper feed characteristics or poor construction and repair techniques. Estimates were that some 3 to 4.5 million digesters were operating in the early 1980s. Since then, research, development, and dissemination activities have focused greater attention on proper construction, operation, and maintenance of digesters. One estimate is that there were some 5 million household digesters in working condition in China as of the mid-1990s. There are in addition some 500 large-scale digesters operating at large pig farms and other agro-industrial sites, and some 14,000 digesters at urban sewage treatment plants.

Several thousand biogas digesters are also operating in other developing countries, most notably South Korea, Brazil, Thailand and Nepal. In addition, there are an estimated 5000 digesters installed in industrialized countries, primarily at large livestock processing facilities (stockyards) and municipal sewage treatment plants. An increasing number of digesters are located at food processing plants and other industrial facilities. Most industrial and municipal digesters are used predominantly for the environmental benefits they provide, rather than for fuel production.

1.3.4 LIQUID BIOFUELS

Biofeuls are produced in processes that convert biomass into more useful intermediate forms of energy. There is particular interest in converting solid biomass into liquids, which have the potential to replace petroleum-based fuels used in the transportation sector. However, adapting liquid biofuels to our present day fuel infrastructure and engine technology has proven to be non- trivial. Only oil producing plants, such as soybeans, palm oil trees and oilseeds like rapeseed can produce compounds similar to hydrocarbon petroleum products, and have been used to replace small amounts of diesel. This “biodiesel” has been marketed in Europe and to a lesser extent in the U.S., but it requires substantial subsidies to compete with diesel. Another family of petroleum-like liquid fuels that is produced from gasified biomass is a class of synthesized hydrocarbons called Fischer-Tropsch (F - T) liquids. The process synthesizes hydrocarbon fuels (C10 - C11 hydrocarbons (kerosene) or C3 - C4 hydrocarbons (LPG)) from carbon monoxide and hydrogen gas over iron or cobalt catalysts. F - T liquids can be used as a sulfur-free diesel or blended with existing diesel to reduce emissions, an environmental advantage, but it has yet to be produced efficiently and economically on a large scale, and research and development (R&D) efforts are ongoing. In addition, to use as an automotive fuel F-T liquids can potentially be used as a more efficient, cleaner cooking fuel than traditional wood fuels from which it is synthesized.

Other alternative biofuels to petroleum-based fuels are alcohols produced from biomass, which can replace gasoline or kerosene. The most widely produced today is ethanol from the fermentation of biomass. In industrialized countries ethanol is most commonly produced from food crops like corn, while in the developing world it is produced from sugarcane. Its most prevalent use is as a gasoline fuel additive to boost octane levels or to reduce dependence on imported fossil fuels. In the U.S. and Europe the ethanol production is still far from competitive when compared to gasoline and diesel prices, and the overall energy balance of such systems has not been very favorable. The Brazilian Proalcool ethanol program, initiated in 1975, has been successful due to the high productivity of sugarcane, although subsidies are still required. Two other potential transportation biofuels are methanol and hydrogen. They are both produced via biomass gasification and may be used in future fuel cells.

While ethanol production from maize and sugarcane, both agricultural crops, has become widespread and occasionally successful it can suffer from commodity price fluctuation relative to the fuels market. Consequently, the production of ethanol from lignocellulosic biomass (such as wood, straw and grasses) is being given serious attention. In particular, it is thought that enzymatic hydrolysis of lignocellulosic biomass will open the way to low cost and efficient production of ethanol. While the development of various hydrolysis techniques has gained attention in recent years, particularly in Sweden and the United States, cheap and efficient hydrolysis processes are still under development and some fundamental

issues need to be resolved. Once such technical barriers are surmounted and ethanol production can be combined with efficient electricity production from unconverted wood fractions (like the lignine), ethanol costs could come close to current gasoline prices and overall system efficiencies could go up to about 70 percent (low heating value). Though the technology to make this an economically viable option still does not exist, promising technologies are in the works and there are currently a number of pilot and demonstration projects starting up.

2.4 IMPLEMENTATION OF BIOMASS ENERGY SYSTEMS

Raw biomass has several disadvantages as an energy source. It is bulky with a low energy density and direct combustion is generally highly inefficient (other than advanced domestic heaters) producing high levels of indoor and outdoor air pollution. The goal of modernized biomass energy is to increase the fuel's energy density while decreasing its emissions during production and use. Modernizing biomass energy production however faces a variety of challenges that must be adequately addressed and dealt with before the widespread implementation of bioenergy systems can occur. These issues include technical problems (just discussed), resource availability, environmental impacts, and economic feasibility.

2.4.1 BIOMASS RESOURCES

Biomass resources are potentially the largest renewable global energy source, with an annual primary production of around 4500 EJ with a bioenergy potential on the order of 1900 EJ, of which about 170 EJ could be considered available on a sustainable basis. The challenge is not the availability so much as the sustainable management and conversion and delivery to the consumer in the form of modern and affordable energy services. Most of the biomass used today is either a residue in a bioprocessing industry or is an opportunity fuel that is used in households for daily living needs. It is argued that if biomass is to become a major fuel in the world, as is being proposed in future energy scenarios, then residues will not suffice and energy plantations may need to supply up to 80 percent of the future feedstock.

The solar energy conversion efficiency of plants is low, in practice less than 1 percent. Consequently relatively large land surfaces are required to produce a substantially amount of energy. Moreover biomass has a low energy density. For comparison: coal has an energy density of 18 GJ/ton, mineral oil of 41 GJ/ton, liquified natural gas of 51 GJ/ton while biomass is only 8 GJ/ton of wood (50 percent moisture content). Consequently transportation becomes an essential element of biomass energy systems, with transportation distances becoming a limiting factor, both from an economic and energetic point of view. While generally it has been found that for woody biomass the energy output is 10-30 times greater than the energy input necessary for fuel production and transport, the issue is less clear for the production of liquid fuels, except ethanol from sugarcane, which does have high net energy yields.

At present the production of biomass residues and wastes globally, including byproducts of food, fiber and forest production exceeds 110 EJ/year, perhaps 10 percent of which is used for energy. Residues concentrated at industrial sites are currently the largest commercially used biomass source. Residues are not, however, always accessible for energy use. In some cases collection and transport costs are prohibitive; in other cases, agronomic considerations dictate that residues be recycled to the land. In still other cases, there are competing non-energy uses for residues (e.g., fodder, construction material, industrial feedstock, etc.).

Residues are an especially important potential biomass energy source in densely populated regions, where much of the land is used for food production. In fact, biomass residues play important roles in such regions precisely because the regions produce so much food: crop production can generate large quantities of byproduct residues. For example, in 1996 China generated crop residues in the field (mostly corn stover, rice straw, and wheat straw) plus agricultural processing residues (mostly rice husks, corn cobs, and bagasse) totaling about 790 million tonnes, with a corresponding energy content of about 11 EJ. To put this in perspective, if half of this resource were to be used for generating electricity at an efficiency of 15 percent (achievable at small scales today), the resulting electricity generation would be about half of the total electricity generated from coal in China in 1996.

There is also a significant potential for providing biomass for energy by growing crops specifically for that purpose. The IPCC's biomass intensive future energy supply scenario discussed previously includes 385 million hectares of biomass energy plantations globally in 1050 (equivalent to about one-quarter of present planted agricultural area), with three-quarters of this area established in developing countries. Such levels of land use for bioenergy raises the issue of intensified competition with other important land uses, especially food production. Competition between land use for agriculture and for energy production can be minimized if degraded land and surplus agricultural land are targeted for energy crops. In developing countries in aggregate there are about 1 billion hectares of land that have been classified as degraded. While there are many technical, socioeconomic, political, and other challenges involved in successfully growing energy crops on degraded lands, the feasibility of overcoming such challenges is demonstrated by the fact that successful plantations have already been established on degraded lands in developing countries.

There are two approaches to producing energy crops. These include devoting an area exclusively to production of such crops, and co-mingling the production of energy and non-energy crops, either on the same piece of land (agro-forestry) or on adjacent pieces of land (farm forestry). Since energy crops typically require several years to grow before the first harvest, the second approach has the benefit of providing the energy-crop farmer with revenue from the land between harvests of energy crops. In Sweden productive heat power generation from willow plantations has been successful, and there has also been experience in small-scale fuelwood production in India, China, and elsewhere. While in Brazil farm forestry activities have involved small farmers in the high-yield production of biomass feedstocks.

2.4.1. ENVIRONMENTAL IMPACTS AND BENEFITS

In general renewable forms of energy are considered “green” because they cause little depletion of the Earth’s resources, have beneficial environmental impacts, and cause negligible emissions during power generation. Yet, while biomass is in principle renewable and can have positive environmental impacts if managed properly it also shares many characteristics with fossil fuels, both good and bad. While it can be transported and stored allowing for heat and power generation on demand, modernized bioenergy systems can also have negative environmental impacts associated both with the growing of the biomass and with its conversion to energy carriers.

Environmental impacts of biomass production must be viewed in comparison to the likely alternative impacts (locally, regionally, and globally) without the bioenergy system in place. For example, at the local or regional level, the relative impacts of producing bioenergy feedstocks will depend not only on how the biomass is produced, but also on what would have happened otherwise. Through life cycle analysis (LCA) studies it has been found that where biomass displaces fossil energy systems there will be a reduction in the impact on global climate through a reduction in overall greenhouse gas emissions, but for other types of emissions (i.e., NOx, SO1, N1O) the picture is less clear and is strongly dependent on the source of the biomass, technical details of the conversion process, and the fossil fuel being displaced.

Many bioenergy conversion technologies offer flexibility in choice of feedstock and the manner in which it is produced. In contrast, most agricultural products are subject to rigorous consumer demands in terms of taste, nutritional content, uniformity, etc. This flexibility makes it easier to meet the simultaneous challenges of producing biomass energy feedstocks and meeting environmental objectives. For example, unlike the case with food crops, there are good possibilities for bioenergy crops to be used to revegetate barren land, to reclaim water logged or salinated soils, and to stabilize erosion-prone land. Biomass energy feedstocks when properly managed can both provide habitat and improve biodiversity on previously degraded land.

Erosion and removal of soil nutrients are problems related to the cultivation of annual crops in many regions of the world. While relative to a healthy natural ecosystem bioenergy systems may increase erosion and deplete soil nutrients and quality, bioenergy production on degraded or erosion-prone lands can instead help stabilize soils, improve their fertility, and reduce erosion. Perennial energy crops (unlike food crops) improve land cover and form an extensive root system adding to the organic matter content of the soil. Also removal of soil during energy crop harvest can be kept to a minimum since roots are left in place, and twigs and leaves can be left to decompose in the field enhancing the soil’s nutrients. This helps prevent diseases and improve the soil fertility and quality. Environmental benefits of biomass crops, for carbon sequestration, biodiversity, and landscape and soil stabilization can be particularly significant if plantations are established on intensively managed agricultural land. While energy crops can be harvested by coppicing every few years (three or four) the stools (rootstocks) can survive for many decades, or even centuries becoming significant carbon sinks. In addition, there are considerable benefits for both landscape and biodiversity when native species are used. For example in Europe it would be preferable to grow willows and poplars rather than eucalyptus. Willows in particular support a high biomass and diversity of phytophagous insects, which in turn can support an important food web with many bird species. Also when feasible the recycling of ashes from the biomass combustion can return crucial trace elements and phosphates to the soil. This is already common practice in countries like Sweden and Austria where part of the ashes are returned to the forest floors, and in Brazil, where stillage, a nutrient rich remainder of sugar cane fermentation, is returned to sugar cane plantations.

Another important potential impact from bioenergy feedstock production is the introduction of agricultural inputs into the environment such as fertilizers and pesticides. Fertilizers and the use of pesticides can adversely affect the health of people, water quality, and plant and animal life. Specific effects strongly depend on the type of chemical, the quantities used and the method of application. Current experience with perennial crops (like Willow, Poplar or Eucalyptus) suggests that those crops meet very strict environmental standards. Compared to food crops like cereals application rates of agrochemicals per hectare are a factor 5-10 lower for perennial energy crops. The abundant use of fertilizers and manure in agriculture has led to considerable environmental problems in various regions in the world: nitrification of groundwater, saturation of soils with phosphate, leading to eutrophication and problems in meeting drinking water standards. Also, the application of phosphates has led to increased heavy metal flux to the soil.

Energy farming with short rotation forestry and perennial grasses, however, requires less fertilizer than conventional agriculture. With perennials better recycling of nutrients is obtained. The leaching of nitrogen relating to Willow cultivation can be about a factor of 1-10 less than for food crops and is able to meet stringent standards for groundwater protection.

Possibly the biggest concern, and often considered the most limiting factor to the spread of bioenergy crops, is the demand on available water supplies, particularly in (semi-) arid regions. The choice of a certain energy crop can have a considerable effect on its water-use efficiency. Certain Eucalyptus species for example have very good water-use efficiency when the amount of water needed per ton of biomass produced is considered. But a Eucalyptus plantation on a large area could increase the local demand for ground water and effect groundwater level. On the other hand, energy crops on previously degraded land will improve land cover, which generally has positive effects on water retention and micro-climate conditions. Impacts on the hydrological situation therefore always need to be evaluated on local level.

Finally, there is the issue of biodiversity and landscape. Biomass plantations are frequently criticized because the range of biological species they support is much narrower than natural ecosystems. While generally true, this is not always relevant. It would be if a virgin forest were to be replaced by a biomass plantation -- a situation which would be undesirable. However, when plantations are established on degraded lands or on excess agricultural lands as is intended to be the case, the restored lands are very likely to support a more diverse ecology compared to the original situation. The restoration of such land is generally desirable for purposes of water retention, erosion prevention and (micro-) climate control. Furthermore, a good plantation design, including areas set aside for native flora and fauna, fitting into the landscape in a natural way can avoid the problems normally associated with monocultures. The presence of natural predators (e.g. insects) can prevent the outbreak of pests and diseases. This issue needs more research where specific local conditions, species, and cultural aspects are taken into account.

In addition to the environmental concerns of land and water quality from biomass production there are also strict air quality standards that must be met during biomass to energy conversion processes. Luckily, air emissions can be counteracted with relatively well-understood and largely available technology much of which has been developed and implemented in the fossil fuels industry. Unfortunately, it is expensive to implement in some cases. For example, although the technology to meet strict emission standards is available for small (less than 1 MW) conversion systems, it still can have a serious impact on the investment and operational costs of these systems.

2.4.3. ECONOMIC AND PRODUCTION ISSUES

A number of key areas can be identified which are essential for the successful development and implementation of sustainable, economically competitive bioenergy systems.

The main barrier is whether the energy carriers produced are competitive. This is particularly true when specially produced biomass is used. In many situations where cheap or negative cost biomass wastes and residues are available, the utilization of biomass is or could be competitive and future technology development should help further reduce the costs of bioenergy. In Sweden and Denmark, where a carbon and energy tax has been introduced, more expensive wood fuels and straw are now being used on a large scale. However, on a worldwide basis, the commercial production of energy crops is almost non-existent. Brazil is a major exception where subsidies have been introduced to make ethanol from sugarcane competitive with gasoline.

Closely related to the cost issue are the availability and the full-scale demonstration of advanced conversion technology that combines a high efficiency and an environmentally sound performance with low investment costs. This is essential for competition with fossil fuels when relatively high-cost energy crops are used as energy sources. Advances in the combustion and co-combustion of biomass can considerably increase the attractiveness of combustion as a conversion technology. However, the development and the application of the IGCC technology have the potential to attain higher conversion efficiency at lower costs. Demonstration and commercialization of this technology are therefore important.

Experience with dedicated fuel supply systems based on 'new' energy crops like perennial grasses and short rotation crops (SRC) are very limited compared to the experience of cultivating traditional food crops and forestry techniques. Improvement of yields, increased pest resistance, management techniques, reduction of inputs and further development of machinery are all necessary to lower costs and raise productivity. The same is true for harvesting, storage and supply logistics. Bioenergy systems are complex in terms of organization and the number of actors that can be involved in a total energy system. The biomass is most likely to be produced by farmers or foresters while transport and storage are likely to be the responsibility of another party, and utilities may be responsible for the energy production. The combination of the utilities on the one hand and the agricultural system on the other will create a number of non-technical barriers that have to be dealt with for any future system to work.

The externalities of bioenergy, which are not accounted for in its cost, are important to consider as well and can offer benefits compared to fossil fuels. Its carbon neutral character is one of those externalities. Furthermore, biomass has a very low sulfur content. Another aspect is that biomass is available to most countries, while fossil fuels need to be imported from a limited number of suppliers. Indigenous production of energy has macro-economic as well as employment benefits. Biomass production systems can offer relatively large numbers of unskilled jobs, which can be important for many developing countries. Although there are environmental impacts related to bioenergy (as discussed in the previous section) it is usually considerably more beneficial in terms of external costs than coal, gas, and oil.

Countries where commercialized bioenergy applications have started to play a significant role in the energy system have all implemented strong policies. A carbon tax, price support, long running R&D programs can lead to a powerful combination of gaining experience, building an infrastructure, developing technology and at the same time developing the national market. The Scandinavian countries, Brazil and to a somewhat lesser extent Northwest Europe and the U.S., show that "modernization" is essential to realize the promise of biomass as an alternative energy source. Modernization requires environmentally friendly and sustainable high yield biomass production, efficient conversion to clean energy carriers, and efficient end use.

2.5 CONCLUSIONS

Biomass is one of the renewable energy sources that is capable of making a large contribution to the world's future energy supply. Land availability for biomass production should not be a bottleneck, provided it is combined with modernization of conventional agricultural production. Recent evaluations indicate that even if land surfaces of 400-700 million hectares were used for biomass production for energy about halfway the next century, this could be done without conflicting with other land-use functions and nature preservation. Partially this can be obtained by better agricultural practices, partially by making use of huge areas of unproductive degraded lands. Latin America, Africa, Asia and to a lesser extent Eastern Europe and North America represent a large potential for biomass production.

The forms in which biomass can be used for energy are diverse and optimal resources, technologies and entire systems will be shaped by local conditions, both physical and socio- economic. Perennial crops in particular may offer cheap and productive biomass production systems with low or positive environmental impacts. Technical improvement and optimized production systems along with multifunctional land-use could bring biomass close to the costs of fossil fuels.

A key issue for bioenergy is that its use must be modernized to fit into a sustainable development. Conversion of biomass to energy carriers like electricity and transportation fuels will give biomass a commercial value and provide income for local rural economies. In order to obtain such a situation it is essential that biomass markets and necessary infrastructure are built up, key conversion technologies like IGCC technology and advanced fuel production systems for methanol, hydrogen and ethanol are demonstrated and commercialized, and that much more experience is gained with biomass production systems in a wide variety of contexts. Although the actual role of bioenergy will depend on its competitiveness versus fossil fuels and agricultural policies, it seems realistic to expect that the current contribution of bioenergy will increase during this century.

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