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Biomass Utilization, Limits of

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GLOSSARY

Biodiversity	All species of plants, animals, and microbes in one ecosystem or world.
Biogas	A mixture of methane and carbon dioxide produced by the bacterial decomposition of organic wastes and used as a fuel.
Biomass	Amount of living matter, including plants, animals, and microbes.
Energy	Energy is the capacity to do work and includes heat, light, chemical, acoustical, mechanical, and electrical.
Erosion	The slow breakdown of rock or the movement and transport of soil from one location to another. Soil erosion in crop and livestock production is considered serious worldwide.
Ethanol	Also called ethyl alcohol. A colorless volatile flammable liquid with the chemical formula C_2H_5OH that is the intoxicating agent in liquors and is also used as a solvent.
Methanol	Also called methyl alcohol. A light volatile flammable liquid with the chemical formula CH_3OH that is used especially as a solvent, antifreeze, or denaturant for ethyl alcohol and in the synthesis of other chemicals.
Pollution	The introduction of foreign, usually man-made, products or waste into the environment.
Pyrolysis	Chemical change brought about by the action of heat.
Subsidy	A grant or gift of money.

THE interdependency of plants, animals, and microbes in natural ecosystems has survived well for billions of years even though they only captured 0.1% of the sun's energy. All the solar energy captured by vegetation and converted into plant biomass provides basic resources for all life, including humans. Approximately 50% of the world's biomass is used by humans for food plus lumber and pulp and medicines, as well as support for all other animals and microbes in the natural ecosystem. In addition some biomass is converted into fuel.

Serious shortages of biomass for human use and maintaining the biodiversity in natural ecosystems now exist throughout the world. Consider that more than 3 billion humans are now malnourished, short of food, and various

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essential nutrients. This is the largest number and proportion of malnourished humans ever recorded in history. Meanwhile, based on current rates of increase, the world population is projected to double to more than 12 billion in approximately 50 years. With a population growth of this magnitude, the numbers of malnourished could reach 5 billion within a few decades. The need for biomass will continue to escalate.

Associated with increasing human numbers are diverse environmental problems, including deforestation, urbanization, industrialization, and chemical pollution. All these changes negatively impact on biomass production that is vital to human life and biodiversity. However, at present and in the foreseeable future the needs of the rapidly growing human population will stress biomass supplies. In our need to supply food and forest products for humans from biomass, intense competition between human needs for food and the conversion of biomass into an energy resource is expected to intensify in the coming decades.

Furthermore, human intrusion throughout the natural environment is causing a serious loss of biodiversity with as many as 150 species being lost per day. The present rate of extinction of some groups of organisms is 1000–10,000 times faster than that in natural systems. Ecosystem and species diversity are the vital reservoir of genetic material for the successful development of agriculture, forestry, pharmaceutical products, and biosphere services in the future.

The limits of biomass energy utilization and how this relates to food production and natural biodiversity and environmental quality are discussed in this article.

I. BIOMASS RESOURCES

The amount of biomass available is limited because plants on average capture only about 0.1% of the solar energy reaching the earth. Temperature, water availability, soil nutrients, and feeding pressure of herbivores all limit biomass production in any given region. Under optimal growing conditions, natural and agricultural vegetation and produce about 12 million kilocalories per hectare per year (about 3 t/ha dry biomass).

A. World Biomass

The productive ecosystems in the world total an estimated 50 billion hectare, excluding the icecaps. Marine ecosystems occupy approximately 36.5 billion hectare while the terrestrial ecosystems occupy approximately 13.5 billion hectare. Gross primary productivity for the marine ecosystem is estimated to be about 1 t/ha/yr, making the total biomass production about 36.5 billion metric tons or 145×10^{15} kcal/yr. In contrast, the terrestrial ecosystem produces about 3 t/ha/yr, making the total biomass about 40.5 billion tons or 162×10^{15} kcal/yr. The total biomass produced is approximately 77 billion tons or about 12.8 t per person per year.

The 40.5 billion tons of biomass produced in the terrestrial ecosystem provides an estimated 6.8 t/yr per person. Given that humans harvest about 50% of the world's terrestrial biomass, each person is utilizing 3.4 t/yr. This 3.4 t/yr includes all of agriculture, including livestock production and forestry. The remaining 3.4 t/yr per person supplies the other 10 million species of natural biota their energy and nutrient needs.

Currently, approximately 50% of the world's biomass (approximately 600 quads worldwide) is being used by humans for food, construction, and fuel. This major utilization of biomass, habitat destruction associated with the rapid increase in the world population, and environmental pollution from about 100,000 chemicals used by humans is causing the serious loss of biodiversity worldwide. With each passing day an estimated 150 species are being eliminated because of increasing human numbers and associated human activities, including deforestation, soil and water pollution, pesticide use, urbanization, and industrialization.

B. United States Biomass

In the North American temperate region, the solar energy reaching a hectare of land per year is 14 billion kilocalories. However, plants do not grow during the winter there. Most plant growth occurs during 4 months in the summer when about 7 billion kilocalories reach a hectare. In addition to low temperatures, plant growth is limited by shortages of water, nitrogen, phosphorus, potassium, and other nutrients, plus the feeding pressure of herbivores and disease organisms. At most, during a warm moist day in July a plant, like corn, under very favorable conditions, might capture only 5% of the sunlight energy reaching the plants. Under natural and agricultural conditions for the total year, vegetation produces approximately 12 million kilocalories per hectare per year or about 3 t/ha dry biomass.

Total annual biomass produced in the United States is an estimated 2.6 billion tons (Table I). This is slightly more than 6% of all the terrestrial biomass produced in the world. Based on the United States. land area of 917 million hectares, this is the equivalent of 2.9 t/ha/yr and is similar to the world average of 3 t/ha/yr for all the terrestrial ecosystems of the world. The total energy captured by all the United States plant biomass each year is approximately 11.8×10^{15} kcal (Table I). With the United States currently consuming 87 quads (21.8×10^{15} kcal)

TABLE I Annual Biomass Production in the United States

	Land area (10^6/ha)	Biomass production (10^6/t)
Cropland and crops	192	1,083
Pasture and forage	300	900
Forests	290	580
Other	135	68
Total area	917	—
Total biomass	—	2,631
Total energy (10^{15}/kcal)	11.8	
Biomass production (t/ha)	2.9	

From

Au: Source line - which Ref- possibly 1998?

of fossil energy each year, this means that it is consuming 85% more fossil energy than the total energy captured by all its plant biomass each year.

C. United States Agricultural and Forest Products and Biofuels

Including crops and forages from pastures, the United States harvests approximately 1307 million tons of biomass per year in agricultural products and approximately 100 million tons of biomass per year as forest products (Table II). Together the energy value of harvested agricultural and forest products total 6352 10^{12} kcal/yr (Table II). These data suggest that the United States is harvesting in the form of agricultural and forest products, 54% of the total energy captured each year by the United States biomass annually (Tables I and II). This total does not include the biomass harvested now and used as biofuel.

II. CONVERSION OF BIOMASS RESOURCES

In addition to using biomass directly as food, fiber, lumber, and pulp, biomass is utilized as a fuel. The total biofuel utilized in the United States is slightly more than 3 quads (800×10^{12} kcal) per year. If the biofuel energy is added to that harvested as agricultural and forest products, then the total biomass energy harvested from the United States terrestrial ecosystem is 7332×10^{12} kcal/yr. This is equivalent to 62% of the total biomass energy produced in the United States each year. Harvesting this 62% is having a negative impact on biodiversity in the nation.

A. Direct Heating

Heat production is the most common conversion system for using biomass resources. Heat from wood and other biomass resources is utilized for cooking food, heating homes, and producing steam for industry.

Each year, worldwide, an estimated 5300 million dry tons of biomass are burned directly as a fuel, providing about 88 quads of energy. Rural poor in developing countries obtain up to 90% of their energy needs by burning biomass. In developing countries, about 2 billion tons of fuelwood, 1.3 billion tons of crop residues, plus nearly 1 billion tons of dung are burned each year.

Although some deforestation results from the use of fuelwood, the most significant environmental impacts result from burning crop residues and dung. When crop residues and dung are removed from the land and used as a fuel this leaves the cropland without vegetative protection and exposed to wind and water erosion. Erosion destroys the productivity of cropland, by robbing the soil of nutrients, essential water, soil organic matter, and adequate rooting depth.

Cooking requires relatively large amounts of fuel and is essential for preventing disease, improving nutrition, and increasing the palatability of many foods. The transfer of heat from the woodfire in a stove to the food product is about 33% efficient, while over an open fire, the heat transfer to the food is only about 10% efficient. Under usual cooking conditions, from 2 to 3 kcal are required to cook 1 kcal of food.

TABLE II Total Annual Amount of Solar Energy Harvested in the Form of Agricultural and Forest Biomass

Au: TCH Tons (10^6) - should be 10^6 - something after slash? Need perm?

	Tons (10^6)	Energy (10^{12}/kcal)
Corn	194	873
Wheat	71	320
Rice	6	27
Soybeans	51	230
Sorghum	22	99
Potatoes	16	72
Vegetables	6	27
Fruits	5	23
Nuts	0.8	4
Oil seeds	9	41
Sugarcane	2.5	20
Sugar beets	2	27
Pulses	1	5
Oats	7	32
Rye	1	5
Barley	13	59
Total	**407.3**	**1,853**
Pasture forage	900	4,050
Forest products	100	450
Totals	**1,407**	**6,352**
Total per capita (tons)	5.2	
Total per capita (10^6/kcal)	23.3	

[From Pimentel, D., and Kounang, N. (1998), *Ecosystems*, **1,** 416–426.]

In a developing country an average, 600–700 kg/yr of dry biomass per person is used for cooking. For example, the use of fuelwood for cooking and heating in Nepal is about 846 kg/yr of biomass per person. Other investigators report that from 912 to 1200 kg/yr of biomass per person is used for both cooking and heating. In some developing countries, fuelwood for cooking and heating may cost almost as much as the food, making it necessary to use crop residues and dung.

A significant amount of wood is converted into charcoal for cooking and heating. Similar to wood fires for cooking, open charcoal fires are only about 10% efficient in transferring heat energy to food. However, charcoal has some advantages over wood. First, it is lightweight and easy to transport. One kilogram of charcoal contains about 7100 kcal of potential energy in contrast to a kilogram of wood that has about 4000 kcal. Charcoal burns more uniformly and with less smoke than wood.

However, charcoal production is an energy-intensive process. Although charcoal has a high energy content, from 20,300 to 28,400 kcal of hardwood must be processed to obtain the 7100 kcal of charcoal. Considering this low conversion efficiency ranging from 25 to 35%, charcoal heating for cooking has an overall energy transfer efficiency to food of only 2.5–3.5%. Further, the use of charcoal uses more forest biomass than directly burning the wood.

Using fuelwood for the production of steam in a boiler under relatively optimal conditions is 55–60% efficient, that is, burning 4000 kcal of air-dried wood provides from 2200 to 2400 kcal of steam in the boiler. More often the efficiency is less than 55–60%. Steam production is used to produce electricity and producing a salable product, such as steam, for industrial use.

Collecting biomass for fuel requires a substantial amount of time and human effort. For example, in Indonesia, India, Ghana, Mozambique, and Peru families spend from 1.5 to 5 hrs each day collecting biomass to use as a fuel.

Estimates are that more than half of the people who depend on fuelwood have inadequate supplies. In some countries, such as Brazil, where forest areas are at present fairly abundant, the rural poor burn mostly wood and charcoal. However, in many developing countries crop residues account for most of the biomass fuel, e.g., 55% in China, 77% in Egypt, and 90% in Bangladesh. Estimates are that the poor in these countries spend 15–25% of their income for biomass fuel.

B. Health Effects

Environmentally, burning biomass is more polluting than using natural gas, but less polluting than coal. Biomass combustion releases more than 200 different chemical pollutants into the atmosphere. The pollutants include, up to 14 carcinogens, 4 cocarcinogens, and 6 toxins that damage cilia, plus additional mucus-coagulating agents. Wood smoke contains pollutants known to cause bronchitis, emphysema, cancer, and other serious illnesses.

Globally, but especially in developing nations where people cook with fuelwood over open fires, approximately 4 billion humans suffer continuous exposure to smoke. This smoke which contains large quantities of particulate matter and more than 200 chemicals, including several carcinogens, results in pollution levels that are considerably above those acceptable by the World Health Organization (WHO). Worldwide fuelwood smoke is estimated to cause the death of 4 million children each year worldwide. In India, where people cook with fuelwood and dung, particulate concentrations in houses are reported to range from 8300 to 15,000 μg/m^3, greatly exceeding the 75 μg/m^3 maximum standard for indoor particulate matter in the United States.

Because of the release of pollutants, some communities in developed areas, such as Aspen, CO, have banned wood burning for heating homes. When biomass is burned continuously in a confined space for heating, its pollutants accumulate and can become a serious health threat.

C. Ethanol Production

Numerous studies have concluded that ethanol production does not enhance energy security, is not a renewable energy source, is not an economical fuel, and does not insure clean air. Further, its production uses land suitable for crop production and causes environmental degradation.

The conversion of corn and other food/feed crops into ethanol by fermentation is a well-known and established technology. The ethanol yield from a large plant is about 9.5 l (2.5 gal) from a bushel of corn of 24.5 kg (2.6 kg/l of ethanol). Thus, a hectare of corn yielding 7965 kg/ha could be converted into about 3063 l of ethanol.

The production of corn in the United States requires a significant energy and dollar investment (Table III). For example, to produce 7965 kg/ha of corn using conventional production technology requires the expenditure of about 10.4 million kcal (about 10,000 l of oil equivalents) (Table III), costing about $857.17 for the 7965 kg or approximately 10.8¢/kg of corn produced. Thus, for a liter of ethanol, the corn feedstock alone costs 28¢.

The fossil energy input to produce the 7965 kg/ha corn feedstock is 10.4 million kilocalories or 3408 kcal/l of ethanol (Table III). Although only 16% of United States corn production is currently irrigated, it is included in the analysis, because irrigated corn production is energy costly. For the 150 mm of irrigation water applied and

TABLE III Energy Inputs and Costs of Corn Production per Hectare in the United States

Inputs	Quantity	kcal × 1000	Costs
Labor	11.4 hr[a]	561[f]	$100.00[h]
Machinery	55 kg[a]	1,018[e]	103.21[m]
Diesel	42.2 L[b]	481[e]	8.87[i]
Gasoline	32.4 L[b]	328[e]	9.40[i]
Nitrogen	144.6 kg[c]	2,668[g]	89.65[i]
Phosphorus	62.8 kg[c]	260[g]	34.54[i]
Potassium	54.9 kg[c]	179[g]	17.02[i]
Lime	699 kg[c]	220[e]	139.80[n]
Seeds	21 kg[a]	520[e]	74.81[l]
Herbicides	3.2 kg[s]	320[e]	64.00[j]
Insecticides	0.92 kg[s]	92[e]	18.40[j]
Irrigation	150 mm[q]	3,072[q]	150.00[r]
Electricity	13.2 kg[b]	34[e]	2.38[k]
Transportation	151 kg[d]	125[e]	45.30[o]
Total		10,439	$857.17
Corn yield		27,758	
= 7,965 kg[p]	kcal output/kcal input = 1 : 2.66		

Au: a -s Refs are not in bib.

[a] From Pimentel, D., and Pimentel, M. (1996). "Food, Energy, and Society," Colorado University Press, Boulder.

[b] USDA (1991).

[c] USDA (1997).

[d] Goods transported include machinery, fuels, and seeds that were shipped an estimated 1000 km.

[e] Pimentel, D. (1980).

[f] It is assumed that a person works 2000 hr/yr and utilizes an average of 10,200 l of oil equivalents per year.

[g] FAO (1999).

[h] It is assumed that farm labor is paid $10/h.

[i] Hinman, et al. (1992).

[j] It is assumed that herbicide and insecticide prices are $20/kg.

[k] Price of electricity is 7¢/kWh (USBC, 1998).

[l] USDA (1998b).

[m] Hoffman, et al. (1994).

[n] USDA (1999).

[o] Transport was estimated to cost 30¢/kg.

[p] USDA (1998a).

[q] The energy data were calculated assuming a pumping depth of 30.5 m (100 ft) for the complete irrigation of a corn crop grown under arid conditions, but this was reduced to 15% because only this is the percentage of corn acreage that is irrigated. Calculation based on data from Peart et al. (1994).

[r] Estimated based on data in Pimentel, et al. (1997b).

[s] National Agricultural Statistic Service (1999).

pumped from only 30.5 m (100 feet), the average energy input is 3.1 million kilocalories/hectare (Table III).

When investigators ignore some of the energy inputs in biomass production and processing they reach an incomplete and deficient analysis for ethanol production. In a recent USDA report, no energy inputs were listed for machinery, irrigation, or for transportation. All of these are major energy input costs in United States corn production (Table III). Another way of reducing the energy inputs for ethanol production is to arbitrarily select lower production costs for the inputs. For instance, Shapouri et al. list the cost of a kilogram of nitrogen production at 12,000 kcal/kg, considerably lower than FAO, which list the cost of nitrogen production at 18,590 kcal/kg. Using the lower figure reduces the energy inputs in corn production by about 50%. Other workers have used a similar approach to that of Shapouri et al.

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The average costs in terms of energy and dollars for a large (240 to 280 million liters per year), modern ethanol plant are listed in Table IV. Note the largest energy inputs are for corn production and for the fuel energy used in the fermentation/distillation process. The total energy input to produce 1000 l of ethanol is 8.7 million kilocalories (Table IV). However, 1000 l of ethanol has an energy value of only 5.1 million kilocalories. Thus, there is a net energy loss of 3.6 million kilocalories per 1000 l of ethanol produced. Put another way, about 70% more energy is required to produce 1000 l of ethanol than the energy that actually is in the ethanol (Table IV).

In the distillation process, large amounts of fossil energy are required to remove the 8% ethanol out of the 92% water. For example, to obtain 1000 l of pure ethanol with an 8% ethanol concentration out of 92% water, then this ethanol must come from the 12,500 l of ethanol/water mixture. A total of 124 l of water must be eliminated per liter of ethanol produced. Although ethanol boils at about 78°C, in contrast to water at 100°C, the ethanol is not extracted from the water in one distillation process. Instead, about 3 distillations are required to obtain the 95% pure ethanol that can be mixed with gasoline. To be mixed with gasoline, the 95% ethanol must be further processed with more energy inputs to achieve 99.8% pure ethanol. The

TABLE IV Inputs per 1000 l of Ethanol Produced from corn[a]

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Inputs	Kilograms	Kilocalories (1000)	Dollars
Corn	2,600	3,408[b]	$280[b]
Transport of corn	2,600	312[c]	32[d]
Water	160,000[e]	90[e]	20[d]
Stainless steel	6[e]	89[e]	10[d]
Steel	12[e]	139[e]	10[d]
Cement	32[e]	60[e]	10[d]
Coal	660[e]	4,617[e]	40[d]
Pollution control costs	—	—	60[d]
Total		8,715	$462

[a] Outputs: 1000 l of ethanol = 5,130,000 kcal.

[b] Table 3.

[c] Estimated.

[d] Pimentel et al. (1988).

[e] Slesser and Lewis (1979).

three distillations account for the large quantities of fossil energy that are required in the fermentation/distillation process. Note, in this analysis all the added energy inputs for fermentation/distillation process are included, not just the fuel for the distillation process itself.

This contrasts with Shapouri et al. who, in 1995, give only one figure for the fermentation/distillation process and do not state what the 3.4 million kilocalories represents in their analysis for producing 1000 l of ethanol. Careful and detailed analyses and full accountings are needed to ascertain the practicality of ethanol production as a viable energy alternative.

About 61% of the cost of producing ethanol (46¢ per liter) in such a large-production plant is for the corn substrate itself (28¢/l) (Table IV). The next largest input is for coal to fuel the fermentation/distillation process, but this was only 4¢ (Table IV). These ethanol production costs include a small charge for pollution control (6¢ per liter), which is probably a low estimate. In smaller plants with an annual production of 150,000 l/yr, the cost per liter increases to as much as 66¢ per liter. Overall, the per liter price for ethanol does not compare favorably with that for the production of gasoline fuels which presently is about 25¢ per liter.

Based on current ethanol production technology and recent oil prices, ethanol still costs substantially more to produce in dollars than it is worth on the market. Clearly, without the approximately $1 billion subsidy, United States ethanol production would be reduced or cease, confirming the fact that basically ethanol production is uneconomical. Federal subsidies average 16¢ per liter and state subsidies average 5¢ per liter. Because of the relatively low energy content of ethanol, 1.5 l of ethanol is the energy equivalent of 1 l of gasoline. This means that the cost of subsidized ethanol is 68¢ per liter. The current cost of producing gasoline is about 25¢ per liter.

At present, federal and state subsidies for ethanol production total about $1 billion per year and are mainly paid to large corporations (calculated from the above data). The costs to the consumer are greater than the $1 billion per year used to subsidize ethanol production because of increased corn prices. The resulting higher corn prices translate into higher meat, milk, and egg prices because currently about 70% of the corn grain is fed to United States livestock. Doubling ethanol production can be expected to inflate corn prices perhaps as much as 1%. Therefore, in addition to paying tax dollars for ethanol subsidies, consumers would be paying significantly higher food prices in the market place. It should be noted that the USDA is proposing to increase the subsidies to the large corporations by about $400 million per year.

Currently about 3.8 billion liters of ethanol are being produced in the United States each year. This amount of ethanol provides only about 1% of the fuel utilized by United States automobiles. To produce the 3.8 billion liters of ethanol we must use about 1.3 million hectares of land. If we produced 10% of United States fuel the land requirement would be 13 million hectares. Moreover not all the 3.8 billion liters would be available to use, because a lot would be needed to sow, fertilize, and harvest 13 million hectares. Clearly, corn is not a renewable resource for ethanol energy production.

The energy and dollar costs of producing ethanol can be offset in part by the by-products produced, especially the dry distillers grains (DDG) made from dry-milling that can be fed primarily to cattle. Wet-milling ethanol plants produce such by-products as corn gluten meal, gluten feed, and oil. Sales of the by-products help offset the energy and economic costs of ethanol production. For example, use of by-products can offset the ethanol production costs by 8–24% (Table IV). The resulting energy output/input comparison, however, remains negative (Table IV). The sales of the by-products that range from13 to 16¢ per liter do not make ethanol competitive with gasoline.

Furthermore, some of the economic and energy contributions of the by-products are negated by the environmental pollution costs associated with ethanol production. These are estimated to be about 6¢ per liter (Table IV). In United States corn production, soil erodes about 12 times faster than it can be reformed. In irrigated corn acreage, ground water is being mined 25% faster than its natural recharge rate. This suggests that the environmental system in which corn is being produced is being rapidly degraded. Further, it substantiates the finding that the United States corn production system is not sustainable for the future, unless major changes are made in the cultivation of this major food/feed crop. Corn should not be considered a renewable resource for ethanol energy production.

When considering the advisability of producing ethanol for automobiles, the amount of cropland required to grow corn to fuel each automobile should be understood. To clarify this, the amount of cropland needed to fuel one automobile with ethanol was calculated. An average United States automobile travels about 16,000 km/yr and uses about 1900 l/yr of gasoline. Although 8000 kg/ha of corn will yield about 3100 l of ethanol, it has an energy equivalent of only 1952 l because ethanol has a much lower kilocalories content than gasoline.

However, even assuming *zero* or no energy charge for the fermentation and distillation process and charging *only* for the energy required to produce corn (Table III), the net fuel energy yield from 1 ha of corn is 433 l. Thus, to provide 1900 l per car, about 4.4 ha of corn must be grown to fuel one car with ethanol for one year. In comparison, only 0.6 ha of cropland is currently used to feed each American. Therefore, more than seven times more cropland would be required to fuel one automobile than is required to feed one American.

Assuming a net production of 433 l of fuel per corn hectare and if all automobiles in the United States were fueled with ethanol, then a total of approximately 900 million hectares of cropland land would be required to provide the corn feedstock for production. This amount of cropland would equal nearly the total land area of the United States.

Brazil had been a large producer of ethanol, but has abandoned subsidizing it. Without the subsidy, economic ethanol production is impossible.

III. BIOGAS

Biomass material that contains large quantities of water can be effectively converted into usable energy using naturally occurring microbes in an anaerobic digestion system. These systems use feedstocks, like dung and certain plants such as water hyacinth, although production and harvesting costs of the latter are generally greater than for dung. The processing facility can be relatively simple and be constructed for about $700. A large facility capable of processing the dung from 320 cows might cost about $150,000. The basic principles for both systems are similar.

Manure from a dairy farm or small cattle operation is loaded or pumped into a sealed, corrosion-resistant digestion tank where it is held from 14 to 28 days at temperatures from 30 to 38°C. In some digestion systems, the manure in the tank is constantly stirred to speed the digestion process and assure even heating. During this period, the mesophilic bacteria break down volatile solids (VS) in the manure and convert them into methane gas (65%) and carbon dioxide (35%). Small amounts of hydrogen sulfide may also be produced. This gas is drawn off through pipes and either burned directly, similar to natural gas, or scrubbed to clean away the hydrogen sulfide and used to generate electricity. The energy output/input is listed in Table V.

The amount of biogas produced in this system is determined by the temperature of the system, the VS content of the feedstock, and the efficiency of converting it into biogas. This efficiency varies from 18 to 95%. Dairy cows produce 85 kg daily of manure for each 1000 kg of live weight. The total solids in this manure average 10.6 kg, and of these, 8.6 kg are VS. Theoretically, a 100% efficient digester could produce 625 l of biogas for every kilogram of VS in the system. The digester utilized for the data presented in Table V was 28.3% efficient. It produces 177 l of biogas per kilogram of VS added or 1520 l of biogas per 1000 kg live weight of cattle daily. Note, if the total heat value of the manure was used in calculating efficiency, then the percentage efficiency would be only 5%.

TABLE V Energy Inputs Using Anaerobic Digestion for Biogas Production from 100 t wet (13 t dry) using Cattle Manure (Pimentel et al., 1988)[a,b]

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	Quantity	kcal (1,000)
Inputs		
Labor hours	20 hr	—
Electricity	2,234 kWh	5,822
Cement foundation (30-year life)	0.9 kg	2
Steel (gas collector and other equipment with 30-year life)	35 kg	725
Pumps and motors	0.5 kg	1
Truck/tractor for transport (10-year life)	10 kg	200
Fuel for transport (10-km radius)	34 l	340
Total inputs		7,090
Total biogas output		10,200

[a] The retention time in the digester is 20 days. The unit has the capacity to process 1,825 t (wet) per year. Note: the yield in biogas from 100 t is estimated at 10.2 million kilocalories. Thus, the net yield is 3.1 million kilocalories. The energy for heating the digester is cogenerated from the cooling system of the electric generator.

[b] It is assumed that anaerobic digestion of the manure takes place at 35°C with a solids retention time of 20 days. The temperature of the fresh manure is 18°C, and the average ambient temperature is 13°C. The manure is assumed to have the following characteristics: production per cow per day, 23.6 kg total; solids, 3.36 kg; and biological oxygen demand (BOD), 0.68 kg. The digester is assumed to transform 83% of the biodegradable material into gas. The biogas produced is 65% methane, and its heat of combustion is 5720 kcal/m^3 at standard conditions.

Biogas has an energy content of about 5720 kcal/m^3, compared to 8380 kcal/m^3 for pure methane gas, because carbon dioxide is present in the biogas. Energy costs and energy outputs for processing 100 t of manure (wet), with a 7.1 million kilocalories energy input, results in a total of 10.2 million kilocalories produced for a net energy yield of 3.1 million kilocalories (Table V). Much of the energy input or cost comes from the production of electricity to run the pumps and stirring system used to reduce the retention time in the digester. The volume of the digester is determined by the amount of manure produced by the animals during the retention time. In this example, with a retention time of 14 days, it would be slightly over 75 m^3. It is assumed that the electricity is generated from the biogas and that the electrical conversion efficiency of the entire operation is 33%. The energy needed to heat the digester is cogenerated by the electric generator via the use of the generator's cooling system as the heat source. The net energy produced by the digester can either be used to generate electricity for the farm or be used as heat source for other on-farm activities.

Although material costs are lowered if there is no generator or stirring mechanism on the digester, the size of the digester must be increased because of the increased retention time needed to complete the process. Also, some of the biogas will have to be used to heat the digester, perhaps an additional 610,000 kcal for every 100 wet tons of manure digested. The critical heat requirements are calculated by including the heat losses to the surroundings, the heat associated with the feed and effluents, and the heat released by the biological reaction. In the tropics, the overall efficiency of the biogas systems is enhanced because there is no need to heat the system to keep the temperature in the 30–38°C range.

Dairy cattle are not the only source of manure for biogas systems. They are used as a model since dairy animals are more likely to be located in a centralized system, making the collecting and adding the manure to a digestion system less time consuming and energy intensive than for range-fed steers, or even for draft animals. Efficiencies of conversion vary not only from system to system, but also the sources of manure. Swine and beef cattle manure appears to yield more gas per kilogram of VS than dairy cattle manure. Poultry manure is also used, but sand and other forms of heavy grit in this dung cause pump maintenance problems and require more frequent cleaning of the digester.

Manure processed in the digester retains its fertilizer value and has the advantage of less odor. Therefore, it can be spread on fields and may be easier to pump if the initial pumping system used a cutter pump to break up stray bits of straw or long undigested fibers. Biogas systems have the advantage of being able to adjust in size according to the scale of the operation. The pollution problem associated with manure in a centralized dairy production system is the same whether or not it goes through a biogas generator.

In developing countries, such as India, the situation is different. There, a substantial percentage of the manure as dried dung is burned directly as fuel. Although burning utilizes a significantly higher percentage of the total energy in the manure, it results in a complete loss of nitrogen and loss of substantial amounts of the other valuable nutrients. Whether or not biogas is a useful energy alternative in India and other similar countries is highly problematic in spite of the higher overall energy efficiency of the conversion system.

If it is not desirable to produce electricity from the biogas, the energy data listed in Table V will change considerably. For instance, less energy will be lost in the conversion to electricity if all the energy is used directly for heating. However, compressing biogas for use in tractors involves the input of significant amounts of additional energy for "scrubbing" the biogas to remove hydrogen sulfide and water.

TABLE VI Energy Inputs for Anaerobic Digester in the Tropics for Biogas Production using 8 t (1 t dry) of Cow Manure (Pimentel et al., 1988)[a]

	Quantity (kg)	kcal
Inputs		
Cement foundation (30-year life)	0.07	140
Steel (30-year life)	0.33	7,000
Total inputs		7,140
Total biogas output		820,000
Net return per 1 t dry manure		812,840

Au: " "

[a] The retention time is 20 days without a means of storing the biogas. The gas is used as delivered. The digestion takes place at 35°C. The temperature of the fresh manure is assumed to be 21°C, and the average ambient temperature is 21°C. The efficiency of the digester is 25%. The biogas produced is 65% methane and its heat of combustion is 5720 kcal/m^3.

A. Biogas for Smallholders

The economics of biogas production in a rural area of a developing nation, like Kenya or India, illustrates that costs and benefits are complex and results mixed. The capital costs of constructing a simple biogas digester with a capacity to process 8 t (wet) of manure per 20-day retention time, or 400 kg/day, are estimated to be between $2000 and $2500 (Table VI). Such a unit would have usable life of 30 years, so the capital costs are only $80 per year.

If rural workers construct the biogas generator themselves, material costs might range from $300 to $700. At $400 for materials, without any charge for labor, the investment would be only $14 per year with the costs spread out over the life of the digester.

A digester this size in India, where cows weigh an average of between 225 to 330 kg each, would require access to manure from about 20 cows. This system would produce an estimated 2277 m^3 of biogas per year at a conversion efficiency of 25% (Table VI). The energy value of this gas totals 13.0 million kcal. Assuming $8.38 per 1 million kcal, the economic value of this much energy is $109 per year. Then if no charge is made for labor and dung and the capital cost is assumed to be only $14 per year, the net return is $95 per year. These costs are not equally applicable to Kenya where the energy replacement of biogas in terms of woodfuel saved is appropriate. Using an average of 4000 kcal/kg of woodfuel, this amount of biogas would replace 3 t of wood and since biogas is generally more efficient than wood when used for cooking, the total amount of wood replaced might be double.

Although the labor requirement for the described biogas generator is only 5–10 min/day, the labor input for collecting and transporting biomass for the generator may be significant. If the source for the 400 kg of manure required for the digester was, on average, 3 km from the digester, it would take 2 laborers working an 8-hr day to collect manure, feed it into the digester, and return the manure to cropland where it could be utilized as fertilizer. On a per hour basis, the laborers would have to work for 3¢ per hour for the biogas digester to have costs equal to the amount of gas produced. In some situations, especially in densely populated parts of a country, the amount of transport required will be too costly.

Although the profitability of small-scale biogas production may be low even without the charge of labor, biogas digesters have significant advantages in rural areas. The biomass can be processed and fuel energy obtained without losing the valuable nutrients (N, P, and K) present in the manure. Nitrogen and phosphorus are major limiting nutrients in tropical agriculture and these are returned to the cropland. The only loss that the processed manure has undergone is the breakdown of the fibrous material it contains, making it a less effective agent for the control of soil erosion.

In contrast, when biomass is directly burned as a fuel, both nitrogen and other nutrients are lost to the atmosphere. The nitrogen in the biogas slurry (for the 146 t/yr amounts) would amount to about 3.7 t/yr. This has an energy value of 77 million kcal and market value of $2293. Then if the nitrogen value and the gas value combined, the return for such a system is approximately $2388. The nitrogen fertilizer value of the processed manure makes it worthwhile as a biogas source rather than burning it as a primary fuel cakes. Based on this, each laborer would receive about 60¢ per hour for his work.

The total amount of manure produced annually in the United States is about one billion tons. It would be an achievement to manage to process even half of this in biodigesters. Due to low net yield of energy, as described, even 500 million t of manure, with gas produced at 28% efficiency, would provide energy for a population of 270 million Americans of 0.0076 kW per person per year. This represents only 0.0008% of present net energy use.

B. Gasification

Biomass wood with less than 50% moisture can be heated in the presence of air and gasified. The gas produced can be used to run internal combustion engines and also used as a gas fuel and for other purposes. When used in the internal combustion engine, the gas must be cleaned thoroughly as the several chemical contaminates it contains corrode engines and reduce its efficiency.

A kilogram of air-dried biomass will produce approximately 2000 kcal of clean gas which can generate about 0.8 kWh of net power electricity. The low heating value of the gas-air mixture in a gasoline engine results in derating the engine by 30–40%. This problem can be overcome by supercharging the engine. Using the gas as a mixture in a diesel engine results in derating the engine by only 10% because of its high excess in the gas-air ratio. However, the diesel engine will require a small amount of diesel fuel for ignition.

Although gasifier units can be relatively simple for small-scale operations designed, large-scale systems are most efficient. Thus, about 11.4 kcal of woodfuel is required to produce 1 kcal of gas. If the gas is cleaned, then the net return is diminished. The input : output results in an energy return in terms of wood to gas of 1 : 0.09. The equipment for cleaning the gas is expensive and uneconomical for use in rural areas, especially in developing countries. In addition to using the produced gas for internal combustion engines, it may be utilized as feedstock for various chemical products.

C. Pyrolysis

Air-dried wood or other biomass heated in the absence of oxygen can be converted into oil, gas, and other valuable fuels. The biomass feedstock, before it is fed to the pyrolysis reactor, must be ground or shredded into smaller than 14-mesh size units. Flash pyrolysis takes place at 500°C and under high pressure (101 kPa). After processing the solid char is separated from the fluids produced in a cyclone separator. The char is then used as a heating source for the reactor.

Using dry municipal refuse, the resulting products from a kilogram of biomass are water, 10%; char, 20% (energy content is about 4500 kcal/kg); gas, 30% (energy content is 3570 kcal/m^3); and oil, 40% (energy content is 5950 kcal/kg). Other investigators have reported up to 50% oil production. This gas and oil can be reprocessed, cleaned, and utilized in internal combustion engines.

The oil and gas yield from a rapid processing pyrolysis plant is about 37% or about 2.7 kcal return per kilocalorie invested. Since the plant analyzed in the study was processing city wastes, there was no energy or economic charge for biomass material. However, if tropical dry-wood is used for pyrolysis about 5 kcal of wood is required to produce 1 kcal of oil.

The gas from a gasifier-pyrolysis reactor can be further processed to produce methanol. Methanol is useful as a liquid fuel in suitably adjusted internal combustion engines.

Employing pyrolysis in a suitably large plant to produce methanol would require at least 1250 t of dry biomass per day. Based on tropical dry-wood, about 32 kcal of wood is needed to produce 1 kcal of methanol (or 1 t of wood yields 14 l of methanol). A more recent study reports that 1 t of wood yields 370 l of methanol. In either case, more than 150,000 ha of forest would be needed to supply one plant. Biomass generally is not available in such enormous quantities from extensive forests and at acceptable prices.

If methanol from biomass was used as a substitute for oil (33 quads) in the United States, about 1000 million hectare of forest land per year would be needed to supply the raw material. This land area is much greater than the 162 million ha of United States cropland now in production. Although methanol production from biomass may be impractical because of the enormous size of the conversion plants, it is significantly more efficient than ethanol production using corn based on energy output and economic use of cropland.

D. Vegetable Oil

Processed vegetable oils from sunflower, soybean, rape, and other plants can be used in diesel engines. One major advantage of burning vegetable oils in a diesel engine is that the exhaust smells like cooking popcorn. However, the energetics and economics of producing vegetable oils for use in diesel engines are negative.

Sunflower seeds with hulls have about 25.5% oil. The average yield of sunflower seeds is 1560 kg/ha, and in terms of oil this amounts to 216 l of vegetable oil produced per hectare. This much oil has an energy value of 1.7 million kilocalories which appears promising. However, the energy input to produce this yield of 1560 kg/ha is 2.8 million kcal. Therefore, 65% more fossil energy is used to produce a liter of vegetable oil than the energy potential of the sunflower oil.

A liter of vegetable oil sells for at least $2 whereas a liter of gasoline at the pump today sells for 40¢ per liter. There is no way that vegetable oil will be an economic alternative to liquid fuels in the future.

E. Electricity

Although most biomass will continue to be used for cooking and heating, it can be converted into electricity. With a small amount of nutrient fertilizer inputs, an average of 3 t (dry) of woody biomass can be sustainably harvested per hectare per year, although this amount of woody biomass has a gross energy yield of 13.5 million kilocalories (thermal). The net yield, however, is lower because approximately 33 l of diesel fuel per hectare is expended for cutting and collecting wood for transport. This assumes an 80-km roundtrip between the forest and the electric plant. The economic benefits of biomass are maximized when the biomass is close to the processing plant.

In addition, a small amount of nitrogen fertilizer has to be applied. For bolewood, 1 t contains about 15 kg of N. Thus about 837,000 kcal is required for 3 t of bolewood.

The energy input : output ratio for the system is calculated to be 1 : 6. The cost of producing a kilowatt of electricity from woody biomass ranges from 7–10¢. This is competitive with other electricity production systems that presently have an average cost of 6.9¢ with a range of 5–13¢ per kWh. Approximately 3 kcal of thermal energy is expended to produce 1 kcal of electricity.

Woody biomass could supply the nation with about 5 quads of its total gross energy supply by the year 2050 with the use of approximately 112 million hectare (an area larger than the state of Texas). A city of 100,000 people using the biomass from a sustainable forest (3 t/ha) for fuel would require approximately 220,000 ha of forest area, based on an average electrical demand of 1 billion kilowatthours (860 kcal = 1 kWh). More than 70% of the heat energy produced from burning biomass is lost in its conversion into electricity; this is similar to losses experienced in coal-fired plants. The forest area required to supply this amount of electricity is about the same as that required to supply food, housing, industry, and roadways for a population of 100,000 people.

There are several factors that limit reliance on woody biomass. Some have proposed culturing fast-growing trees in a plantation system located on prime land. These yields of woody biomass would be higher than the average of 3 t/ha and with large amounts of fertilizers and freshwater yields might be as high as 15 t/ha. However, this is unrealistic because this land is needed for food production. Furthermore, such intensely managed systems require additional fossil fuel inputs for heavy machinery, fertilizers, and pesticides, thereby diminishing the net energy available. In addition energy is not the highest priority use of forest wood, but rather for lumber for building and pulp.

The conversion of natural forests into plantations will increase soil erosion and water runoff. Continuous soil erosion and degradation will ultimately reduce the overall productivity of the land. If natural forests are managed for maximal biomass energy production, loss of biodiversity can be expected. However, despite serious limitations of plantations, biomass production could be increased using agroforestry technologies designed to protect soil and conserve biodiversity.

IV. BIOMASS AND THE ENVIRONMENT

The presence of biomass on the land protects not only the land it covers, but also the natural interactions among all species that inhabit the ecosystem. Conversely, the removal of biomass for all purposes, but most especially for energy production, threatens the integrity of the entire natural ecosystem.

A. Soil Erosion

Once the biomass vegetation has been removed from the land area and the land is exposed to wind and rainfall energy, erosion is a major threat. Land degradation by soil erosion is of particular concern to agriculturists and foresters because the productivity of the soil is diminished. Too often soil erosion and the resulting degradation goes unnoticed (note, 1 mm of soil weighs 15 t/ha). Soil reformation is exceedingly slow. Under agricultural conditions, approximately 500 years (range from 200 to 1000 years) are required to renew 2.5 cm (340 t) of topsoil. This soil formation rate is the equivalent of about 1 t/ha/yr. Forest soil re-formation is slower than in agriculture and is estimated to take more than 1000 years to produce 2.5 cm of soil. The adverse effect of soil erosion is the gradual loss of productivity and eventually the abandonment of the land for crop production.

Serious soil erosion occurs on most of the world's agriculture, including the United States where erosion on cropland averages 13 t/ha/yr. In developing countries, soil erosion is approximately 30 t/ha/yr. The rates of erosion are intensifying in developing countries because of inefficient farming practices and because large quantities of biomass are removed from the land for cooking and heating. Rural people who are short of affordable fuels are now being forced to remove crop residues and utilize dung for cooking, leaving their soils unprotected and susceptible to wind and water erosion.

Indeed soil erosion caused by wind and water is responsible for the loss of about 30% of the world cropland during the past 40 years. For example, the rate of soil loss in Africa has increased 20-fold during the past 30 years. Wind erosion is now so serious in China that Chinese soil can be detected in the Hawaiian atmosphere during the Chinese spring planting period. Similarly, soil eroded by wind is carried from Africa to Florida and Brazil.

Erosion diminishes crop productivity by reducing the water-holding capacity of the soil and reduces water availability to the plants. In addition, soil nutrient levels and organic matter are carried away with the eroding soil and soil depth is lessened. Estimates are that the continuing degradation of agricultural land will depress world food production from 15–30% by the year 2020. Others project that Africa will be able to feed only 40% of its population in 2025 both because of population growth and soil infertility in vital cropland areas.

B. Forest Land Erosion

Forestlands lose significant quantities of soil, water, and soil nutrients wherever trees are cut and harvested. For instance, the surface water runoff from a forested watershed after a storm averaged 2.7% of the precipitation, but after forest cutting and/or farming water runoff rose to 4.5 percent. In addition, soil nitrogen leached after forest removal was 6 to 9 times greater than in forests with normal cover.

Also, the procedures used in harvesting timber and pulpwood biomass contribute to increased erosion because they expose the soil to wind and rainfall energy. Typically, tractor roads and skid trails severely disturb 20–40% of the soil surface in forests. In addition, the heavy equipment needed to harvest and clear the land compacts the soil, resulting in greater water runoff.

For example, compaction by tractor skidders harvesting Ponderosa pine reduced growth in pine seedlings from 6 to 12% over a 16-year period. Following clearing, water percolation in the wheel-rutted soils was reduced for 12 years and in log-skid trails for 8 years. This resulted in a lack of water for the remaining vegetation and limits continual forest biomass production.

C. Nutrient Losses and Water Pollution

Rapid water runoff and nutrient losses occur when crop biomass residues are harvested for fuel and rainfall easily erodes soils. Water quickly runs off unprotected soil because raindrops free small soil particles that, in turn, clog holes in the soil and reduce water infiltration. This water runoff transports soil organic matter, nutrients, sediments, and pesticides to rivers and lakes where it harms natural aquatic species. For example, conventional corn production lost an average of about 20 t/ha/yr of soil compared with only about 5 t/ha/yr with ridge- and no-till.

As mentioned, the water-holding capacity and nutrient levels of soils are lessened when erosion occurs. With conventional corn production, erosion reduced the volume of moisture in the soil by about 50% compared with no-till corn culture. In contrast, soil moisture volume increased when corn was grown in combination with living mulches. Estimates are that about $20 billion in fertilizer nutrients are lost annually from United States agriculture because of soil erosion.

Large quantities of nutrients are also lost when fuelwood and crop residues are also removed and then burned. On average, crop residues contain about 1% nitrogen, 0.2% phosphorus, and 1.2% potassium. When burned, the nitrogen is released into the atmosphere. Although some phosphorus and potassium are retained in the ashes, an estimated 70–80% of these nutrients is lost when the fine particulate matter is dispersed into the air during burning process. Thus, only a small percentage of the nutrients in crop residues are conserved even when returning the ash residues to the cropland.

D. Water Use

All biomass vegetation requires and transpires massive amounts of water during the growing season. Agriculture uses more water than any other human activity on the planet. Currently, 65% of the water removed from all sources worldwide is used solely for irrigation. Of this amount, about two-thirds is consumed by plant life (nonrecoverable). For example, a corn crop that produces about 8000 kg/ha of grain uses more than 5 million liters per hectare of water during its growing season. To supply this much water to the crop, approximately 1000 mm of rainfall per hectare, or 10 million l of irrigation, is required during the growing season.

The minimum amount of water required per capita for food production is about 400,000 l/yr. If the water requirements for biomass energy production were added to this, the amount of required water would be more than double to about 1 million l/yr.

In addition to the unpredictable rainfall, the greatest threat to maintaining adequate fresh water supplies is depletion of the surface and groundwater resources that are used to supply the needs of the rapidly growing human population. Aquifers are being mined faster than the natural recharge rate and surface water is also not always managed effectively, resulting in water shortages and pollution that threaten humans and the aquatic biota that depend on them. The Colorado River, for example, is used so heavily by Colorado, California, Arizona, other states, and Mexico, it is usually no more than a trickle running into the Sea of Cortes.

E. Air Pollution

The smoke produced when fuelwood and crop residues are burned is a pollution hazard because of the nitrogen, particulates, and other pollutants in the smoke. A report indicated that although only 2% of the United States heating energy comes from wood, and about 15% of the air pollution in the United States is caused by burning wood. Emissions from wood and crop-residue burning are a threat to public health because of the highly respirable nature of the 200 chemicals that the emissions contain. Of special concern are the relatively high concentrations of potentially carcinogenic polycyclic organic compounds and particulates. Sulfur and nitrogen oxides, carbon monoxide, and aldehydes are also released, but with wood there are usually smaller quantities than with coal.

V. SOCIAL AND ECONOMIC IMPACTS

In the future, if the world biomass is used as a major source of the world energy supply, shifts in employment and increases in occupational health and safety problems can be expected. Total employment would be projected to increase 5% if about 11% of the United States energy needs were provided by biomass. This labor force would be needed in agricultural and forest production to plant, cut, harvest, and transport biomass resources and in the operation of various energy conversion facilities.

The direct labor inputs for wood biomass resources are 2–30 times greater per million kilocalorie than coal. In addition, a wood-fired steam plant requires 2–5 times more construction workers and 3–7 times more plant maintenance and operation workers than a coal-fired plant. Including the labor required to produce corn, about 18 times more labor is required to produce a million kilocalories of ethanol than an equivalent amount of gasoline.

Associated with the possibilities of increased employment are greater occupational hazards. Significantly more occupational injuries and illnesses are associated with biomass production in agriculture and forestry than with either coal (underground mining), oil, or natural gas recovery operations. Agriculture and forestry report 61% more occupational injury and illness rates than mining. In terms of a million kilocalories of output, forest biomass has 14 times more occupational injuries and illnesses than underground coal mining and 28 times more than oil and gas extraction. Clearly, unless safe harvesting practices and equipment are developed and used, increased forest harvesting and agricultural production for energy will result in high levels of occupational injuries and increased medical expenditures and workman compensation.

The future development of major biomass energy programs will require large amounts of cropland suitable for biomass production and ultimately result in increased prices for some consumer commodities. The use of commodities, especially grains, for energy leads to competition with traditional uses of these commodities. Thus, with increased grain use for ethanol production, inflation of farm commodity prices could result. This in turn would increase farmland prices and make it more difficult for new farmers to enter the business and for existing small farmers to cope with higher rents, taxes, interest payments, and production costs. Food prices in supermarkets would be expected to increase.

VI. CONCLUSION

Certainly increased use of biomass as a fuel could provide the United States and the world with more renewable energy. A major limitation of biomass energy production includes the relatively small percentage (average 0.1%) of light energy that is captured by the earth's plant material. This governs how much biomass can be produced per unit land area. In addition to solar energy, suitably warm temperature conditions, adequate amounts of water, and the absence of pests are essential for plant growth. In North America, for example, plant growth only occurs for approximately three months of the year. In arid regions of the world plant growth is restricted only to periods of adequate rainfall.

The removal of biomass, such as crop residues, from the land for energy production intensifies soil erosion, water runoff, and soil nutrient losses. In addition, the conversion of natural ecosystems into energy-crop plantations would alter and/or reduce the habitat and food sources for wildlife and biodiversity.

At present, about half of the world's biomass is harvested as food and forest products. Thus, there is a limit as to how much biomass can be harvested as an energy source without further causing the extinction of more plants, animals, and microbes because of biomass resources on which biodiversity depends. Agriculture and managed forests occupy approximately 70% of the total land area and use about 70% of the total water consumed by society, and this further limits natural biodiversity.

However, opportunities do exist to combine agriculture and forest production. If this is to be done several changes would have to be made in many technologies now used in agriculture and forestry. These technologies include conserving soil, water, and nutrient resources. Of particular importance is keeping the land covered with vegetation and maintaining high levels of organic matter in the soil.

Although biomass resources have a lower sulfur content than oil and coal, biomass energy conversion and use has associated environmental and public health problems. For example, the chemical emissions from wood-burning for cooking and heating produce serious chemical pollutants, including some carcinogens and other toxicants. In addition, on the basis of a million kilocalorie output, harvesting forest biomass energy is about 14 times more hazardous than coal and oil mining.

Ethanol production using grains and other food material for gasohol can be expected to have a significant negative impact on social and economic systems. A major ethanol program would help fuel inflation by raising food prices to the consumer. In addition, "burning food" as ethanol in automobiles has serious political and ethical considerations.

In conclusion, the conversion of biomass to provide an energy source has some potential to contribute to world energy needs, but the associated environmental, health, social, and economic problems must be carefully assessed. The foremost priority is the supply of food. Especially vital to this goal is maintaining an ample supply of fertile cropland needed to feed the rapidly growing world population.

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