Professional Sports," *Law and Contemporary Problems* 38 (Winter/Spring 1973), p. 50.

18. This was challenged by several witnesses, including Ed Garvey, executive director of the National Football League Players Association. The Players Association stood in opposition to S.2784 and gave qualified support to S.2821.
19. *Professional Sports, op. cit.*, p. 36.
20. See *Professional Sports, op. cit.*, pp. 214 and 31 for the respective statements.
21. Arthur Johnson, "Congress and Professional Sports: 1951-1978," *ANNALS* (September 1979), pp. 114-115.
22. The City of Oakland refused to accept Finley's offer of a buyout and prevented him from moving his baseball franchise from Oakland.
23. Jesse Markham and Paul Teplitz, *Baseball, Economics and Public Policy* (Lexington, Mass.: Lexington Books, 1982), p. 28.

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Energy Policies and Biomass Resources in the Asia-Pacific Region

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■ Uncertainties in petroleum availability and pricing have stimulated research and development in alternative energy technologies in both industrialized countries and developing countries. The production of energy from renewable natural resources has received considerable attention. The major biomass feedstocks—wood, grass, and crop residues, as well as animal wastes—have been and continue to be important fuels in many countries of the world, although the efficiency with which they are used is low. New demands for alternative energy sources have stimulated research and development for new "energy" species as well as new biomass technologies. However, these developments have the potential for serious environmental degradation, particularly with respect to deforestation in tropical and sub-tropical countries. Indonesia is an example of a country with a great potential for energy from biomass but where that development must be carefully planned in order to prevent major environmental problems. In both developing and industrialized countries, policies which encourage biological and technological developments in the production of energy from biomass in an environmentally sound manner should be supported.

Introduction

The shifts in energy production and distribution that occurred during the 1970s significantly affected the energy policies of most countries. The situation has been particularly difficult in lower income developing countries whose economies are dominated by increasing imports, especially petroleum, and higher prices for commercial energy from non-renewable fossil fuels. Strategies to respond to the short-term crisis include conservation and increased efficiency in the production and use of energy. In the long term, countries may plan an orderly transition to a more sustainable and diversified energy economy that will emphasize the development of new domestic energy supplies from conventional fuels and increased substitution of new and renewable energy resources for commercial supplies.

Energy from biomass has significant potential for more efficient production in the short term and for long-term interfuel substitution. This potential is particularly great in lower income developing countries with highly productive ecosystems. Increased utilization of biomass for energy, however, must be balanced against adverse environmental impacts and conflicts over resource use.

The objective of this paper is to assess the energy potential of traditional biomass resources, especially lignocellulosic materials, of countries in the Asia-Pacific Basin and to examine the issues of resource conflicts that might result from expanded biomass production. These issues include the environmental impacts of large-scale deforestation and the conflicts between using land for food or fuel. Indonesia is presented as an example of the complexity of these issues in a country that, although currently a petroleum exporter, has a tremendous potential for production of biomass resources for long-term energy needs. Policies that have been proposed to encourage the more efficient production and use of biomass energy resources must also mitigate adverse environmental impacts and competition of the use of tropical forest and land resources for food or fuel.

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Bioenergy

Hall states that any energy resource must have certain important characteristics for it to be used as a fuel.[1] Ideally, the resource will be available at many locations and will have a fairly uniform quality. It can be stored for extended periods and yet will be available for use on demand while remaining acceptable to the user in terms of safety and convenience of handling. The energy resource will be applicable to a wide variety of uses in solid, liquid, or gaseous form and can be converted from one form to another while remaining economical in comparison to other energy fuel sources. Finally, the resource should result in minimal negative impact on the environment during mining, drilling, or harvesting and during combustion or conversion to fuel. Compared with non-renewable conventional energy sources, especially fossil fuels, biomass resources meet most of these criteria. In addition, they are renewable.

A wide variety of biomass materials are available as fuel feedstocks (Figure 1). The major resources are wood, crop wastes and residues, and animal wastes. These traditional fuels are especially important in developing countries, where they meet a large portion, if not the majority, of energy needs. Firewood is the primary fuel in rural areas and among the poor, and charcoal is preferred in urban areas. Crop and animal residues are used for fuel when wood (and charcoal) is not available or is too expensive. Dunkerley *et al.* estimated that in 1978, these traditional fuels comprised 28 percent of the total energy supplies in developing countries, with an estimated 80 percent used for cooking.[2]

By comparison, biomass fuels represent only a small fraction of the energy supply and use in developed countries. Although some firewood is used for domestic heating and cooking, it is less than one percent of total energy supplies.[3] Heavy reliance on liquid fuels for transportation has resulted in renewed interests in the production of alcohol (ethanol) fuels from grain and in gasification of lignocellulosic materials. Other processes depend primarily on urban-industrial wastes as fuels. However, the U.S. Congress Office of Technology Assessment (OTA) recently concluded that the bioenergy processes that are expected to be most efficient in displacing large quantities of oil are direct combustion and gasification for process heat and steam.[4] The technologies for efficient wood stoves and wood-fired boilers are well-developed, and for gasifiers are well underway. Some large-scale industrial cogeneration plants that use wood as the primary fuel are in operation.[5]

Lignocellulosic Materials as Biomass Fuels

Wood is the world's oldest energy resource. It is also the dominant source of lignocellulosic materials that can be used as biomass fuels.[6] Wood is renewable, relatively abundant, and widely available. Wood's primary problems as a fuel are its solid form, high moisture content, and relatively low energy content.[7] As a primary fuel, dry wood contains an average energy content of about 19 MJ/kg. Dry grasses contain about 14 MJ/kg whereas dry crop residues and animal wastes, although highly variable, usually are 14 MJ/kg or less. By comparison, the two primary fossil fuels, coal and crude oil, have an average value of 29 MJ/kg and 43 MJ/kg, respectively.

The potential contribution of lignocellulosic material as an energy supply depends on the production of plant biomass and the distribution of the resource base. Photosynthesis, which converts the radiant energy of sunlight to the chemical energy of plants, is the principal biological factor that influences the production of plant biomass. Photosynthesis has two phases: (1) an energy-capturing light phase resulting in the photolysis of water and yielding chemical energy and (2) a carbon dioxide assimilating dark phase. The dark phase has three different biochemical pathways: three carbon (C_3), four carbon (C_4), and Crassulacean acid metabolism (CAM).[8] The C_3 pathway is the most common among the world's plants. The CAM pathway is found in plants such as cacti that are adapted to arid environments. The C_4 pathway is found primarily in tropical grass species. Plants with the C_4 pathway typically can utilize a wider range of light intensities, have a low carbon dioxide compensation point, and have a higher photosynthetic efficiency than C_3 species.[9]

Both biological and environmental factors can be manipulated by management practices such as plant breeding, fertilization, irrigation, pest control, and crop rotation to achieve maximum biomass yields.

In addition to biological factors, the physical environment also influences net biomass productivity. The most important factors are: (1) the intensity and duration of solar radiation, (2) temperature, and (3) the availability of carbon dioxide, water, and soil nutrients. Both biological and environmental factors can be manipulated by management practices such as plant breeding, fertilization, irrigation, pest control, and crop rotation to achieve maximum biomass yields.

The major ecosystems of the earth have an estimated net annual primary biomass production of 164 billion dry tons (Table 1). Tropical forests have the highest range of net primary productivity per unit area and the highest total net production (40 billion dry tons per year) of any of the world's terrestrial ecosystems. Although tropical forests are only 40 percent of the area of the world's forests, they account for 55 percent of the total forest biomass production. The Asia-Pacific region has about 13 percent of its land area in tropical forests and contributes about 25 percent of the annual global tropical forest biomass production.[10]

Estimates of the potential energy resources from lignocellulosic materials and other traditional biomass fuels in developing countries are crude. The lack of accurate, comparable data is a major problem. How-

FIGURE 1
Major Processes for Conversion of Biomass for Fuel (Adapted from Hall, 1981)

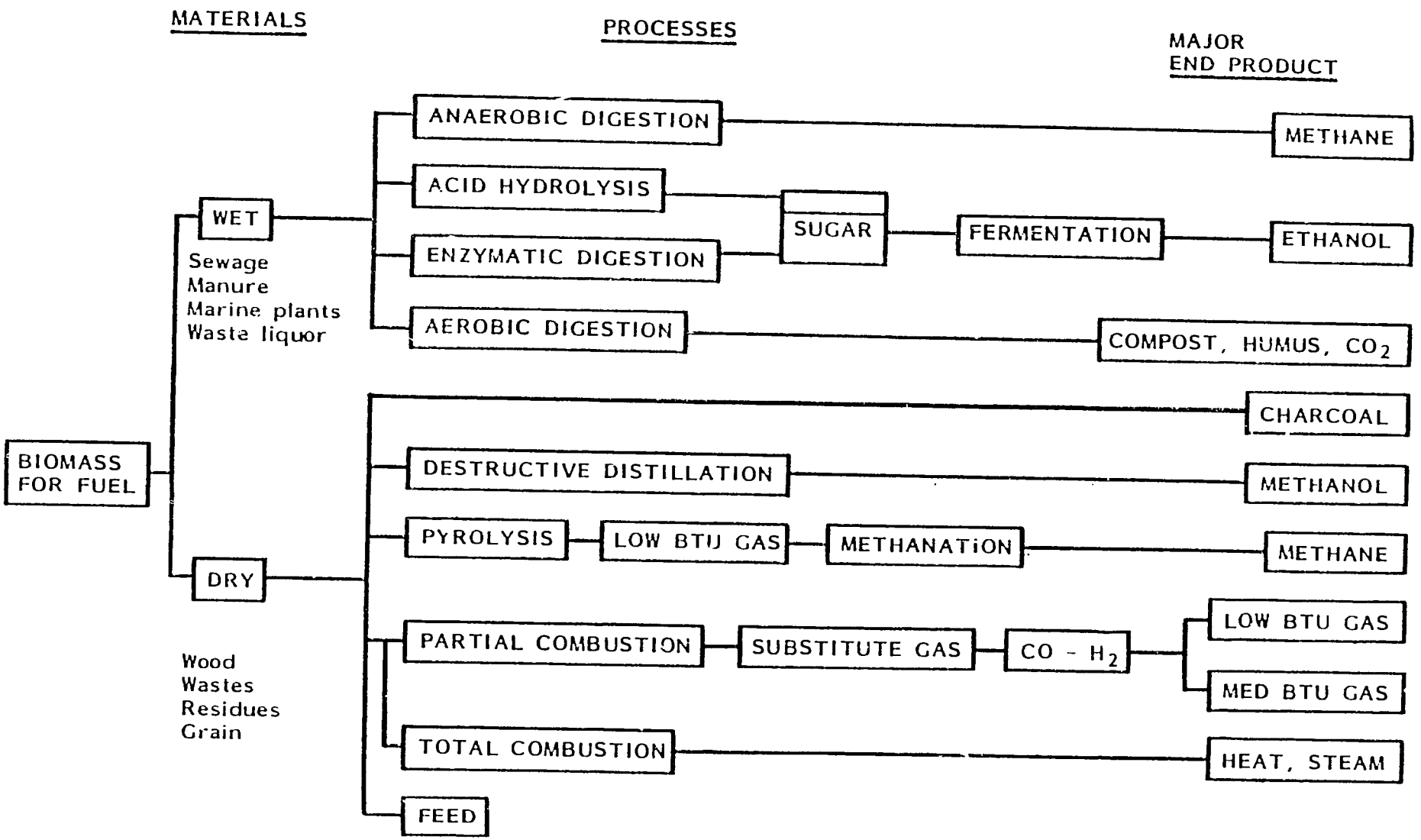

TABLE 1
Net Primary Biomass Production of Major Ecosystems of the Earth's Surface

Type of Ecosystem	Area (millions of square kilometers)	Net Primary Productivity per Unit Area (dry grams per square meter per year)		World Net Primary Production (billions of dry tons per year)
		Normal Range	Mean	
Lake and Stream	2	100-1,500	500	1.0
Swamp and Marsh	2	800-4,000	2,000	4.0
Tropical Forest	20	1,000-5,000	2,000	40.0
Temperate Forest	18	600-3,000	1,300	23.4
Boreal Forest	12	400-2,000	800	9.6
Woodland and Shrubland	7	200-1,200	600	4.2
Savanna	15	200-2,000	700	10.5
Temperate Grassland	9	150-1,500	500	4.5
Tundra and Alpine	8	10- 400	140	1.1
Desert Scrub	18	10- 250	70	1.3
Extreme Desert, Rock, and Ice	24	0- 10	3	0.07
Agricultural Land	14	100-4,000	650	9.1
TOTAL FOR LAND	149		730	109.0
Open Ocean	332	2- 400	125	41.5
Continental Shelf	27	200- 600	350	9.5
Attached Algae and Estuaries	2	500-4,000	2,000	4.0
TOTAL FOR OCEAN	361		155	55.0
TOTAL FOR EARTH	510		320	164.0

Source: R. H. Whittaker, *Communities and Ecosystems* (New York: Macmillan Press, 1970).

ever, Dunkerly *et al.* have compiled estimates for countries in Latin America, Africa, and Asia that compare the relative importance of the annual increment of forest growth to total potential annual energy from biomass (Table 2).[11] The range of the estimates varies by an order of magnitude. For purposes of comparison, the upper estimates will be used. These values assume an annual increment of ten cubic meters of biomass per hectare (a realistic, but conservative value for some tropical forests) and an energy content of 10,000 MJ per cubic meter (also a conservative value).[12] The theoretical annual increment is the amount of energy that could be derived from the biomass actually produced. The estimates reflect the total areal extent of the forests in each country. They are not adjusted to account for the differential productivity of specific forest ecosystems or for any constraints upon use.

The total potential annual biomass energy resource in each region is considerable. The contribution from the theoretical annual increment of forest growth is greatest, in an absolute and in a relative sense, in Latin America and Africa, and least in Asia. The relative importance of manure and residues in the Asian region is the result of large rural populations engaged in intensive agriculture and animal husbandry. Among selected East Asian countries, the Peoples Republic of China (PRC) and India are examples of this case. Deforestation has significantly reduced the size of the resource base for biomass from forest growth. Other countries, especially Indonesia, have a relatively large potential for bioenergy from forests and other lignocellulosic materials. In each case, the potential energy available from the annual increment of forest growth greatly exceeds the estimated annual consumption of fuelwood and charcoal provided that it is available for that use only.

Biomass in the Energy Futures of Developing Countries

In developing countries, energy conservation and increased efficiency in the production and use of traditional fuels has been the most common short-term response to the high cost of commercial energy. However, biomass energy sources may play different roles in the future as socio-economic development results in increased energy demand. Energy price inflation will probably increase the demand for traditional fuels, primarily firewood for people in rural communities and charcoal for poor people in rapidly growing urban centers. The large-scale substitution of other renewables or energy sources for firewood (and charcoal) would be difficult.[13] Consequently, fuelwood collection as a cause of deforestation may increase especially in proximity to cities, with secondary impacts on land and water resources. Deforestation will be especially serious where the loss of forest resources exceeds the annual forest growth increment.

TABLE 2
Potential Annual Renewable Energy Resources from Forests and Waste Biomass in Developing Countries

Continent and Country	Total Forest Area[a]	Theoretical Annual Increment[b]	Potential Annual Energy, by Source[c]				Fuelwood and Charcoal Consumption[e]
			Forest Growth[d]	Manure	Residues	Total Biomass	
Latin America	800.0	800-8,000	8,000-80,000	5,476.0	2,802.0	16,000-88,000	2,500
Africa	795.0	795-7,950	7,950-79,500	2,963.0	895.0	12,000-83,000	3,100
Asia	506.0	506-5,060	5,060-50,600	11,018.0	11,925.0	28,000-74,000	5,600
Selected East Asian Countries							
Burma	45.0	45- 450	450- 4,500	173.0	176.0	800- 4,800	210
China (PRC)	80.0	80- 800	800- 8,000	3,350.0	5,096.0	9,200-16,000	1,500
India	75.4	75- 750	750- 7,500	4,250.0	3,043.0	8,000-15,000	1,300
Indonesia	124.7	125-1,250	1,250-12,500	219.0	559.0	2,000-13,000	1,200
Malaysia	23.6	24- 240	240- 2,400	20.7	40.2	300- 2,500	61
Philippines	15.9	16- 160	160- 1,600	177.0	289.0	630- 2,100	250
Thailand	29.[illegible]	29- 290	290- 2,900	205.0	308.0	800- 3,400	180

[a]In million hectares.

[b]In million cubic meters; volume assessed to be capable of increase at 1-10 cubic meters per hectare.

[c]Values are $\times 10^{15}$ (gigajoules).

[d]Assumes an energy content of 10,000 MJ per cubic meter.

[e]Estimated, 1976-1977, in gigajoules ($J \times 10^{15}$).

Source: Adapted from Dunkerley *et al.* (1981), Table 7-4, pp. 173-177.

If domestic energy demand exceeds the supply of firewood, the rural people will substitute animal and crop wastes. This has already happened in densely-populated Asia-Pacific countries, where fuelwood supplies from tropical forests have either decreased or are expensive because they are relatively inaccessible. Increased use of animal and crop wastes, in turn, can result in loss of soil fertility and crop productivity because traditional supplies of organic materials and soil nutrients that are readily available in rural areas are converted to meet domestic energy needs.

In the long term, developing countries may follow a strategy designed to increase domestic energy supplies. Most countries will probably depend on commercial energy from conventional, nonrenewable fossil fuels and hydroelectric power for their primary energy resources. They may expand domestic energy supplies from conventional resources, including previously unexploited reserves, and increase the role of new and renewable energy resources.[14] Renewable energy resources, especially biomass, have an important potential in tropical Asian countries for expanded and more efficient production. Dunkerly *et al.* recommended that developing countries use biomass to generate electricity, produce alcohol fuels, and increase biomass supplies for traditional uses, with technologies appropriate for village settlements. Furthermore, renewables can be substituted as the primary energy sources where existing commercial fuels are insufficient to meet demand, and too costly, or where the environmental impacts associated with them are unacceptable.[15] Any large-scale development of biomass, however, raises significant issues of adverse environmental impact and competition for land resources to produce food or fuel crops.

Environmental Impacts of Bioenergy

The Office of Technology Assessment of the U.S. Congress has concluded that the environmental impacts from the production and use of bioenergy are potentially less harmful than the most damaging fossil fuel alternative, which is coal.[16] Coal is expected to be the major fuel used for commercial primary energy in the Asia-Pacific region. Although the comparative impacts of energy futures dominated by conventional, nonrenewable resources such as coal and renewables from biomass are not clearly defined, the OTA analysis is instructive (Table 3). Growing and harvesting traditional biomass resources (wood, agricultural products, and residues) primarily involve extending the more intensive applications of present forest management and agricultural practices. Biomass conversion technologies generally leave a lower potential for environmental degradation than coal conversion, and small-size biomass facilities can decentralize, and perhaps also diminish, environmental impacts.[17] Bioenergy, however, is not environmentally benign. Severe environmental damage can result from large-scale production if not properly managed. Bioenergy is also land intensive and may compete for land and other resources that are highly valued for other purposes, especially food production. Consequently, conflicts in resource use, land management practices, and institutional problems of controlling environmental impacts under decentralized production and use are major issues.

The potential environmental impacts vary by type of biomass fuel. The "damage potential" increases from the use of wastes to the use of lignocellulosic materials, including intensively cultured crops that are used for

TABLE 3
Comparison of Biomass and Coal Fuel Cycles

	Biomass	Coal
Land	• large land areas affected • ecosystem displacement and loss of diversity • erosion • esthetic changes • possible soil depletion over the long term	• smaller land areas affected at any one time • reclamation failure and subsidence • erosion • esthetic changes
Water	• biological and chemical oxygen demand from fertilizers and conversion wastes • sediments–major problem without careful management • pesticides	• toxic substances from ash and sludge disposal, synfuels production • sediments–more localized • acid mine drainage
Air	• local problems with unburned hydrocarbons, particulates, CO, H_2S, odors	• local dust problems • problems associated with long-distance transport of sulfur and nitrogen compounds, fine particulates, and possibly oxidants • possibility of climate changes from CO_2 emissions
Institutional	• regulatory difficulties with multiple small sources and nonpoint sources	• more centralized systems may be more amenable to regulation under current programs

ethanol and methanol products. These comparisons are especially significant in regard to the use of tropical forest resources of the Asia-Pacific countries for biomass. Paradoxically, wood is the preferred fuel and the tropical forests, which offer the greatest potential wood resources, face the risk of large potential environmental damages if the demand for bioenergy resources increases. The situation is especially acute in tropical countries where large-scale deforestation has already reduced the amount of land in tropical forests.

The most drastic changes in forest environments today are occurring in tropical forests in developing countries. In some cases tropical forest ecosystems are being modified by small-scale shifting agriculture; in other cases by large-scale land use conversion. In tropical forests, deforestation has resulted from demands for agricultural land, fuelwood supplies, and commercial wood and wood products.[18] Deforestation results in a chain of significant environmental impacts. Removal of the forest canopy increases exposure of understory plants and surface soils to solar energy and rainfall which, in turn, leads to more rapid physical and chemical weathering. Accelerated erosion typically occurs, especially on steeper slopes, resulting in problems of losses of organic matter and soil nutrients and changes in soil texture. Increased downward leaching of soil nutrients may also occur. Deforestation also increases the proportion of overland water flow. With this increased surface water runoff, flooding usually occurs, as do problems with sediment transport and subsequent siltation. Other potential impacts, such as an overall decrease in ecological diversity, climatic changes, and shifts in the global carbon cycle which might occur as a result of large-scale deforestation warrant serious consideration.

The environmental impacts and resource conflicts are expected to increase and become more extensive as the importance of bioenergy in the energy futures of Asia-Pacific countries increases. Land use competition for producing food or fuel resources may be the major conflict. In the short term, the substitution of animal and crop wastes in the case of fuelwood storages illustrates this conflict. Agricultural productivity on land that has been cleared for food production is threatened unless strict soil and energy conservation measures are imposed. In the long term, large-scale bioenergy production poses the conflict of food versus fuel in different terms. Although bioenergy crops would be most productive on the best agricultural lands, they will be assigned to marginal lands, including unimproved forest lands that have, in some way, been deforested. The management of tropical forests for biomass energy resources would preclude the confined expansion of agricultural lands, although not necessarily fuelwood collection. Large-scale silvicultural plantations managed on a sustained yield basis are necessary if biomass resources are to be truly renewable.

Biomass Potential in Indonesia

Indonesia is an example of a country in East Asia that can significantly increase its bioenergy resources in an environmentally sound manner and improve the national energy budget. Indonesia has an estimated 132 million people living on five large islands and a number of smaller islands.[19] Agriculture is the predominant activity and rice is the main crop. Indonesia is also a member of the Organization of Petroleum Exporting Countries (OPEC), with a 1982 production of 498 million barrels of oil that ranked it as the world's 9th

largest oil producer.[20] PERTAMINA, the Indonesian national petroleum company, controlled production.[21]

Indonesia has an estimated 124.7 million hectares of forests. Forests cover 64 percent of the total land area, ranging from 80 percent of Kalimantan to 23 percent of Java and 14 percent of Bali.[22] Trees of the genus *Dipterocarpus* are the dominant woody species of the tropical lowland evergreen rain forests which cover much of Indonesia, Malaysia, and the Philippines. The *Dipterocarpus* forests are known to have standing crop volumes of 500-700 cubic meters per hectare, with a dry mass of 450-800 metric tons per hectare. The average annual incremental growth of these forests is approximately 25 cubic meters (or about 20 metric tons dry weight) per hectare.[23] Thus, the annual incremental biomass productivity per hectare is equivalent in energy content to about 5.75 metric tons of crude oil.

In developing countries, energy conservation and increased efficiency in the production and use of traditional fuels has been the most common short-term response to the high cost of commercial energy.

Estimates of the theoretical annual incremental forest productivity in Indonesia (see Table 2) is equivalent to 290 million metric tons of crude oil. However, if this value is adjusted using the best estimates of the areal extent of forests and the average annual incremental productivity for *Dipterocarpus* forests, the value increases to 707 million metric tons of crude oil. By comparison, Indonesia produced 65 million metric tons (489 million barrels) of crude oil in 1982.

Tropical forests are the major source of firewood in Indonesia. About 97 percent of an estimated 115 million cubic meters of wood consumed annually is for non-industrial purposes, primarily firewood.[24] Firewood supplies approximately 75 percent of the total energy consumption, 93 percent of which is for household cooking. The United Nations' average yield figures for the Asia-Pacific region is 3.1 cubic meters of wood harvested per hectare of forest per year, although Ovington states that this is an underestimate because of lack of records, the use of fuelwood, and other uses by rural people.[25] Indonesian wood has varied uses. However, forest management has focused on industrial wood harvest, with much of the wood exported as logs. Forest plantations and forest plantation management are rare in Indonesia.[26]

Gathering wood for fuel is a major cause of deforestation in Indonesia. In addition, shifting agriculture has changed about 30 million hectares of tropical forests to degraded grasslands or poor quality, mixed, second-growth forests.[27] Another two million hectares of forest are presently being affected by shifting cultivation.[28]

Policies that would encourage reclamation of deforested lands with bioenergy plants would be desirable. Several non-woody species, particularly those with four carbon (C_4) pathways, are promising. Kenaf (*Hibiscus cannabinus*), an annual plant of the family Malvacaeae, has an excellent potential as a bioenergy species.[29] Several tropical species of the genus *Sorghum* are interesting possibilities, although relatively little research has been done on them.

Because it exports petroleum, Indonesia may not vigorously pursue bioenergy programs in order to increase fuel substitution for petroleum. However, the careful development of biomass resources can not only reduce deforestation but also significantly improve reforestation. In Indonesia the annual pattern of rainfall rather than any seasonal temperature pattern regulates agricultural activity. On agricultural lands, the high temperatures lead to rapid chemical weathering and the heavy rainfall in excess of evaporation leads to rapid leaching, both actions reducing the nutrient capital of the soil. The best uses for these nutrient depleted soils is replanting with some tolerant, hardy, perennial species. Some replanting has been done with the rubber tree, *Hevea brasiliensis,* which meets these requirements. However, there is no longer a strong market demand for natural latex.[30]

High productivity, "biomass for energy" species may offer an attractive alternative. For example, if the 30 million hectares in Indonesia which have been deforested were converted to kenaf production, a potential of approximately 672 million metric tons (dry mass), or approximately 219 million metric tons crude oil equivalent, could be harvested per year. By contrast, if the same 30 million hectares were reforested (a slower, more difficult, and more expensive proposition) to reasonably mature, second-growth forests, the potential, annual incremental forest productivity could be approximately equivalent to 172 million metric tons of crude oil.

Policy Issues

A wide variety of new and renewable technologies and energy sources have been considered for use in developing countries.[31] The development of abundant energy resources that are known and are technically feasible should be encouraged. Hydropower is an example. However, policies that encourage the more efficient production and use of traditional fuels in rural areas can have an immediate effect on energy supplies for large numbers of people, and avoid increased dependency on petroleum and other conventional fossil fuels.

Yet, energy from biomass does not offer a panacea for the Asia-Pacific region's developing countries. Policies that are designed to increase the energy contribution of biomass must also avoid the potentially serious adverse environmental impacts that may be associated with bioenergy and resolve the conflicts from the competition for land to produce food or fuel crops. In the developed countries, bioenergy crops can be expected to concentrate on existing agricultural lands. In the Asia-Pacific region, tropical forests have already suffered widespread deforestation and degradation, primarily from the demand for cropland. Agricultural

expansion is projected to continue to be the primary cause of deforestation until 2000, when the demand for fuelwood and forest products may be most important.

Several policies have been proposed for developing countries to encourage more efficient production and use of bioenergy resources from tropical forests in an environmentally sound manner.[32] One set concerns energy supplies:

1. Better management of existing forest resources to increase productivity.
2. Intensive management of silviculture plantations using quick-growing trees and shrubs.
3. New "energy from biomass" species.
4. Reforestation, perhaps with new species and under intensive management.
5. Restrictions on new forest land clearing, based on forest inventories and soil capability studies.

Increased forest productivity though better and increased forest management, higher biomass yields, and production (or restoration) of forest resources can be economically and environmentally profitable for Asia-Pacific region countries. However, each of these policies would restrict, if not eliminate conversion of tropical forest land to agricultural use.

A second set of policies focuses on technological change and innovation. They include:

1. Use of more efficient wood and charcoal cooking stoves.
2. Replace (1) with biogas (i.e., produce cooking gas from animal and crop wastes by biomethanation) and solar stoves.
3. Produce ethanol (from agricultural products) and methanol (from lignocellulosic materials) to substitute for kerosene.

Change in biomass conversion technologies is primarily a socioeconomic issue. Ethanol and methanol production, however, introduce issues of using land for food or fuel crops.

A number of important and encouraging demonstration projects attest to the technical feasibility of some of the proposals for biomass resources production. The diffusion of technological innovation has been successful in some Asian countries, especially India. However, other technologies have been developed to clear tropical forests more rapidly and inexpensively under pressure of growing domestic and foreign demand for wood and wood products. Environmentally significant conservation and reforesting practices cannot be expected unless and until technically competent institutions are provided with adequate resources and authority.

Conclusion

Traditional fuels from biomass—fuelwood, animal wastes, and crop residues—are important energy sources in developing countries. Their importance is expected to increase in the future and focus on lignocellulosic materials, primarily wood. The moist tropical forests are an extraordinarily large and productive resource base for biomass in the Asia-Pacific region. They have also been subject to widespread deforestation, primarily because of the expansion of agricultural land. Policies designed to use forests' biomass resources for energy would result in conflicts over using land for fuel or for food, and they create significant environmental issues, as well.

Bioenergy is not environmentally benign. Although potentially less harmful than coal, the environmental impacts from bioenergy development in the Asia-Pacific region are expected to increase, especially if focused on lignocellulosic materials from the tropical forests. Policies to increase the efficiency of the production and use of biomass energy sources must also include sound environmental management. Energy issues and forestry issues are becoming increasingly intertwined in the developing countries. As increased energy demand focuses on forest resources, forest resources, like natural gas, may soon be too valuable for other uses to be burned for domestic heating and cooking.

Notes

1. These are discussed in C. W. Hall, *Biomass as an Alternative Fuel* (Washington, D.C.: Government Institutes, 1981).
2. J. Dunkerley, W. Ramsey, L. Gordon, and E. Cecelski, *Energy Strategies for Developing Nations* (Baltimore: The Johns Hopkins Press, 1981). See also: *The Global 2000 Report to the President: Entering the Twenty-first Century.* Prepared by the Council on Environmental Quality and the Department of State (Washington, D.C.: U.S. Government Printing Office, 1980).
3. Dunkerley *et al.; op. cit.*
4. U.S. Congress, Office of Technology Assessment, *Energy from Biological Processes,* 2 vols. (Washington, D.C.: U.S. Government Printing Office, 1980).
5. W. D. Betts, "Wood Fuel for Industrial Cogeneration at Dow Corning," in G. L. Fowler and J. C. Randolph (eds.), *Proceedings of a Workshop on Land Use Planning for Coal and Biomass* (Chicago: Midwest Universities Energy Consortium, 1982), pp. 210-216.
6. Lignocellulosic materials include the wide variety of plants whose tissues have high (but varying) amounts of cellulose, hemi-celluloses, and lignins. Usually these materials are found in the stems, branches, and leaves of "woody" plants, although grasses are also included.
7. There is considerable variation among the scientific, engineering, and policy literature as to the units used to describe the energy content of fuels. While almost all countries of the world now use the metric (SI) system, the United States persists with the outdated British system. In the British system, energy content is usually given in either British Thermal Units (BTU) or calories

per unit mass. Energy content in the metric system is usually expressed in either joules per gram (J/g) or megajoules per kilogram (MJ/kg). In addition to these problems with fundamental units, energy contents are often expressed in terms of coal or crude oil equivalents. While such comparisons do permit a concrete reference, they are quite inexact. For example, the range of energy content of two different coals may be as much as 100 percent depending on their carbon, moisture, and ash contents. Thus "average" values are used in these comparisons. One metric ton (approximately 7.5 barrels) of "average" crude oil has an energy content of 43,000 MJ or 10.2×10^6 kilocalories or 40.5×10^6 BTU.

8. There are a number of excellent references which provide more information about the C_3, C_4 and CAM biochemical pathways of photosynthesis; see J. A. Berry, "Adaptation of Photosynthetic Processes to Stress," *Science* 188: 644-650 (1975).
9. The carbon actually fixed by the plant and used in its growth and reproduction of tissues represents the net productivity of the plant. The theoretical efficiency of photosynthesis is 8 percent, although few plants exceed 4 to 5 percent, and the average efficiency of terrestrial plants on a worldwide basis is only about 0.3 percent. Obviously, the efficiency by which a plant species utilizes solar radiation to fix carbon dioxide is a prime determinant in net production and thus biomass yield. See: A. G. Alexander, "Production of Non-woody Plants as a Renewable Energy Source," in D. L. Klass (ed.), *Biomass as a Nonfossil Fuel Source,* ACS Symposium Series, 144: 49-76 (1981).
10. Percentages calculated using data in Tables 1 and 2.
11. J. Dunkerley *et al., op. cit.*
12. The energy content of one cubic meter of fuelwood is approximately equivalent to the energy content of 0.33 metric tons of coal or 0.23 metric tons of crude oil; also see footnote 7.
13. United Nations, General Assembly. *United Nations Conference on New and Renewable Sources of Energy. Report of the Synthesis Group.* CONF. 100/PC/41 (New York: United Nations, 1981).
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