Chapter 1

SUMMARY

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FIGURES

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Energy from the conversion of wood and other plant matter represents an important underexploited resource in the United States. As renewable, abundant, and domestic energy resources, these and other sources of biomass can help the United States reduce its dependence on imported oil. The amount of energy supplied by biomass, now relatively small, could expand rapidly in the next two decades — a period when the Nation's energy problems will be particularly acute.

At present, significant uncertainties about land availability and quality, energy conversion costs, market characteristics, and other factors hinder the analysis of the biomass potential or the way the complex, varied, and interconnected markets will respond to bioenergy development. Although the uncertainties are very real, they are not debilitating. General trends can be discerned and analyses of them can be used in formulating policy, although many of the specific details will have to be refined as more information becomes available. Nonetheless, policy makers will have to weigh the uncertainties carefully in devising workable strategies for promoting bioenergy.

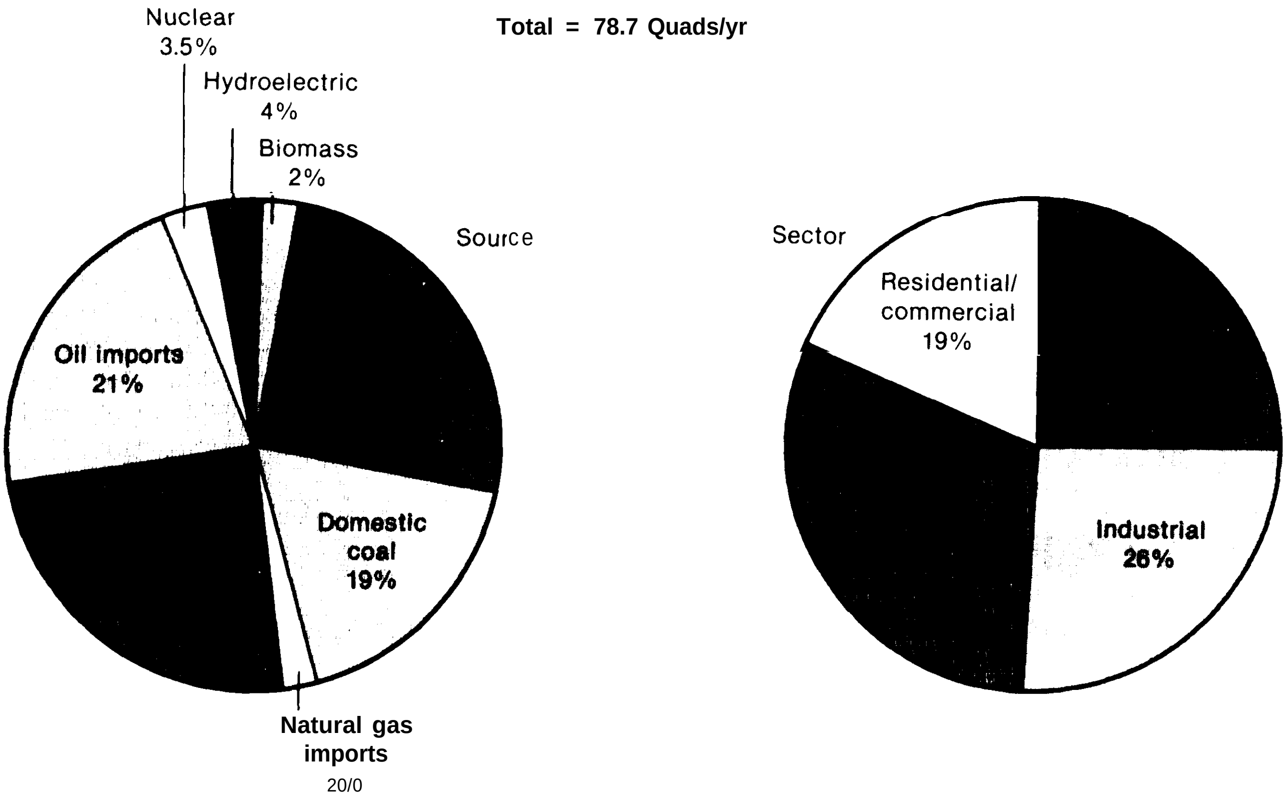
Energy Potential From Biomass

A very substantial amount of energy, as much as 12 to 17 Quads/yr, depending on cropland needs for food production, could be produced from biomass sources in the United States by the year 2000. (Current U.S. energy consumption is **79** Quads/yr (figure 1); oil imports are 7 million bbl/d or about 16 Quads/yr) This energy could come from numerous types of biomass, including wood, grass and legume herbage, grain and sugar c reps, crop residues, animal manure, food-processing wastes, oil-bearing plants, kelp from ocean farms, and many other materials (figure 2). But, the overwhelming majority of this energy would come from woody or lignocellulosic materials such as wood from commercial forests (up to 10 Quads/y r); various types of herbage, especially grasses and legumes, from existing pastureland and hayland (perhaps as much as 5 Quads/yr with proper plant development and a low demand for new cropland for other uses); and crop residues (about 1 Quad/y r).

Consequently, if the United States wishes to attain the full potential of biomass energy in the next 20 years, processes for converting wood, grass, and crop residues to usable energy should be emphasized, and ways of harvesting and collecting these materials must be promoted that will avoid severe environmental damage. Because of the difficulty of collecting large quantities of these materials in a single place, considerable emphasis will have to be placed on process designs that may be applied in small- to medium-scale facilities. The major processes for converting solid biomass fuels to more usable energy forms are direct combustion, airblown gasification, and alcohol fuels synthesis. The principal concerns about harvesting these materials are: 1) that wood from existing forests be collected in a way that maintains the long-term productivity of forestland for all of its uses, and increases, or at least does not hinder, the production of timber suitable for lumber and paper pulp, and 2) that sufficient crop residues be left in place to protect the soil from excessive erosion.

Energy also can be obtained *on* a sustained basis from: 1) grains and sugar crops and some food-processing wastes used to produce ethanol (perhaps 0.2 Quad/y r), 2) animal manure used to produce biogas (up to about 0.3 Quad/yr), and 3) various other processing wastes (less than 0.1 Quad/y r). The energy potential from other sources such as aquatic plants (e. g., kelp) and oil-bearing arid land plants cannot be assessed with any certainty at present, but total energy production from these sources is likely to be small before **2000 (less** than 0,1 Quad by 1990). Finally, municipal solid waste

Figure 1.— U.S. Energy Use in 1979



SOURCE Office of Technology Assessment; and *Monthly Energy* Review, Energy Information Administration, Department of Energy, February 1980

could be a significant source of bioenergy; its potential is discussed in a previous OTA report.

Combustion and Gasification

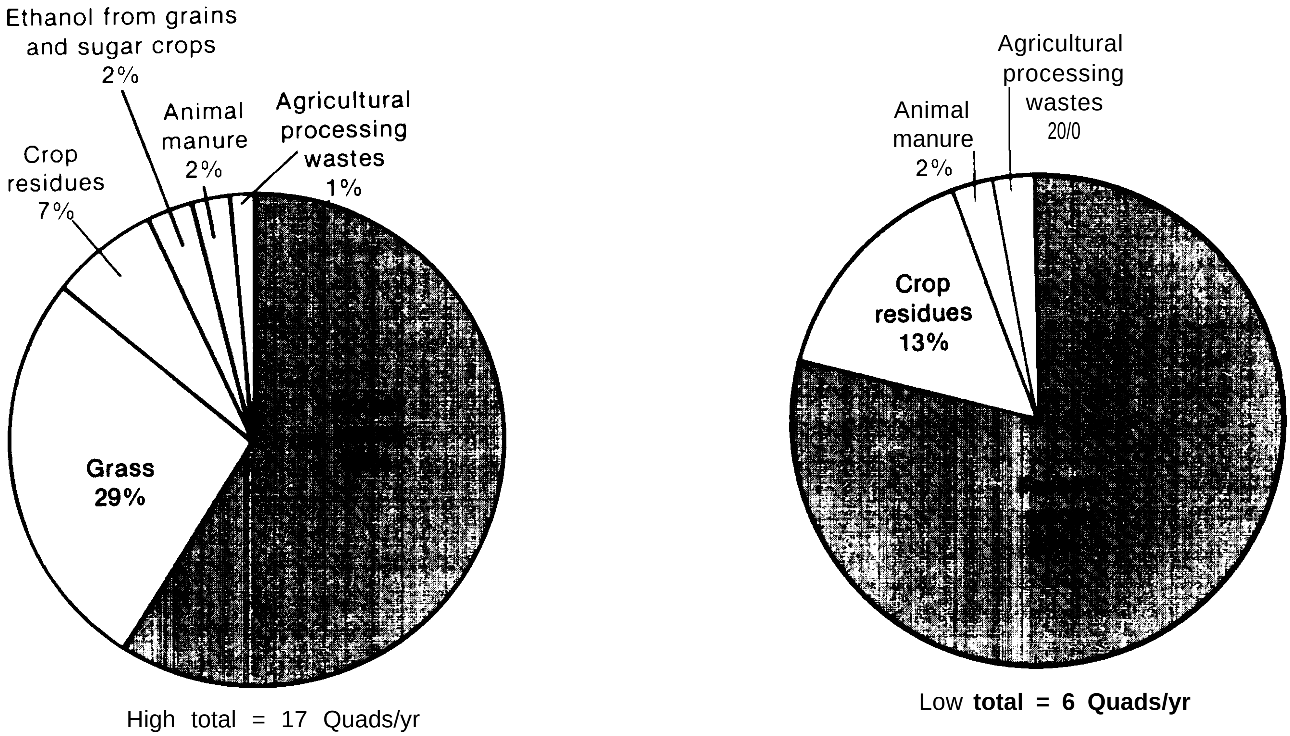
Combustion of wood (including paper-pulping liquor) is the major energy use of biomass today, with about 1.2 to 1.3 Quads used annually for process energy in the forest products industry, and 0.2 to 0.4 Quad/yr in home heating, fireplaces, and other uses (e. g., charcoal grills). Wood combustion, **primarily** in the forest products industry, is likely to expand to 4 to 5.5 Quads/yr by 2000 as a result of increased energy prices without any new Government incentives.

[1] *Energy and Materials From Municipal Solid Waste* (Washington, D.C.: Office of Technology Assessment, July 1979), OTA-M-93

The development of reliable, fairly automatic, airblown gasifiers that can be mass produced and attached directly to natural gas or oil-fired industrial boilers or used for crop drying or other process heat would greatly aid the introduction of energy from wood and other biomass into industrial sectors other than the forest products industry. Gasification of wood or herbage (e. g., grass, crop residues) is more practical for providing process heat than direct combustion. In addition, the cost of converting from oil or gas to a biomass gasifier probably will be lower than the cost of converting to direct combustion in many cases. Some gasifiers are available today, but their widespread acceptance will require further development and demonstration, which may take 2 to 5 years.

Both direct combustion and gasification of wood are economically competitive with combustion of middle distillate fuel oil in many situations today.

Figure 2.— Potential Bioenergy Supplies (not including speculative sources or municipal wastes)



SOURCE Off Ice of Technology Assessment

Photo credit: USDA-Soil Conservation Service

Commercial forests: an excellent source of energy from biomass

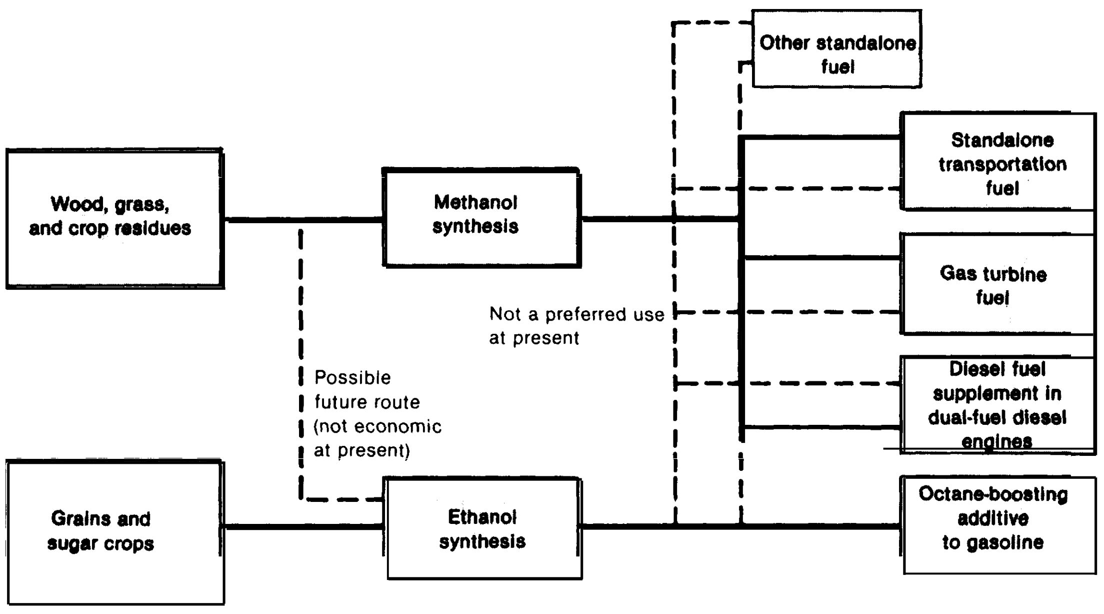
Alcohol Fuels

Biomass conversion to alcohol is the only source of liquid fuels for transportation from solar energy that uses available technology. These liquids are ethanol (grain alcohol) and methanol (wood alcohol) (figure 3). Despite their names, both alcohols can be made from a variety of feedstocks. Methanol can be manufactured from any relatively dry plant material, not just wood, while ethanol can be produced from the same material as well as from grains, sugar crops, and fermentable wastes. Both alcohols can be used as standalone fuels or blended with gasoline. As components of blends, they have the valuable property of raising the octane level of the gasoline to which they are added. The alcohols also could be used as the sole fuel in modified automobiles in captive fleets [over 10 percent of the automobiles), in combustion turbines, and as a diesel fuel supplement in diesel engines built for dual-fuel use.

Because of varying production and delivery costs and differences in the value of alcohol to potential purchasers (including automobile modifications that may be needed to use the fuel), there is no single oil price at which fuel alcohol will suddenly become competitive. However, at corn prices of $2.50/bu, some fuel ethanol from grain could be competitive without subsidies as an octane-boosting additive to gasoline-i. e., in gasohol-at crude oil prices as low as $20/bbl (retail gasoline prices at $1.05 to $1.15/gal). Grain ethanol produced and marketed under less favorable conditions (but at the same corn price) may not be competitive without subsidies until oil prices approached $40/bbl (gas prices at $1.85 to $2.00/gal). Similar "competitive ranges" for both alcohols as stand-alone fuels are $35 to $55/bbl crude oil for methanol and $40 **to $50/bbl crude oil for ethanol (corn at $2.50/bu).** Even when average crude oil prices are in the range given, it must be expected that viable ethanol markets may not exist in some areas with lower than average energy costs, high interest charges, or other less-than-optimum conditions for ethanol production and sales.

Both ethanol and methanol from biomass are likely to be more expensive than methanol from

Figure 3.—Sources and Uses of Alcohol Fuels From Biomass



SOURCE: Off Ice of Technology Assessment.

Photo credit. Iowa *Development Commission*

An hydrous ethanol can be blended with gasoline for direct use in unmodified vehicles

coal. However, unless a liquid fuel surplus develops, all liquid fuel sources-including ethanol and methanol from biomass—will remain important in displacing imported oil, and less expensive coal liquids are not likely to eliminate the need for liquid fuels from biomass.

Currently, the only fuel alcohol being produced from biomass is ethanol from grain and some processing wastes. Total capacity to distill grain into ethanol may reach 100 million to *200* million gal/yr by the end of 1980 (about 0.1 to 0.2 percent of U.S. gasoline consumption). Wood-to-methanol facilities probably can be built with existing technology, although no plants currently exist in the United States. Herbage-to-methanol plants need to be demonstrated.

Onfarm ethanol production is technically possible but currently is constrained by practical and economic considerations. What is needed is the development of highly automatic distilling equipment that is small, safe, and inexpensive, and can produce dry ethanol as well as dry distillers' grain using crop residues, grasses, wood, or solar heat as fuels. In addition, farmers will need technical assistance to ensure safe and efficient operation and maintenance of such equipment. Nevertheless, some farmers already are proceeding with on-farm distillation because it provides them with some degree of liquid fuel self-sufficiency and it allows the diversion of limited quantities of grain to energy.

At ethanol production levels as low as 2 billion gal/yr–but possibly higher if certain market adjustments prove to be feasible–competition between food and energy uses for American grain harvests could begin to drive up grain prices. This finding is based on an economic model that uses conservative but plausible assumptions. In cases of severe food-fuel competition, consumers could end up paying several dollars in higher food costs for each gallon of grain ethanol produced. This indirect cost could make ethanol the most expensive synthetic fuel. Because of the uncertainties about the actual level of ethanol production at which the food-fuel competition will become severe, Congress may wish to carefully monitor the U.S. and international grain markets and reexamine ethanol production incentives as production moves above *2* billion gal/yr.

More optimistic appraisals indicate that higher levels of ethanol production from corn are possible without affecting food prices significantly. This higher threshold is based on optimistic assumptions about the extent to which the corn distillery byproduct will reduce demand for soybeans and about the cost of bringing new cropland into production. Although corn-soybean switching reduces the acreage of new cropland needed to meet both feed and fuel demands, serious questions remain about how much substitution *actually* will occur, the price incentives needed to cause the shift, the productivity of new cropland, and other factors that could reduce crop switching's theoretical potential. Until these matters are resolved, it would appear imprudent to assume that crop switching can allow higher levels of ethanol production without major impacts on food and feed prices.

It also has been suggested that ethanol distilleries could switch to wood or herbage (using processes currently under development) when competition with food develops. OTA's analysis indicates, however, that significant food price increases could precede the commercial availability of competitive wood or herbage-to-ethanol processes. Although some of the technologies currently under development may provide competitive processes before this occurs, there are still substantial economic uncertainties. Moreover, the investment needed for the switch could be very high–nearly as much as the initial investment in the grain-based distilleries.

Another concern with ethanol from grains and sugar crops — more so than with methanol production from wood and herbage — is the energy balance. About the same amount of energy is required to grow these crops and convert them to ethanol as is contained in the ethanol itself. Nonetheless, a net savings of *premium fuels* (oil and natural gas) can be achieved in most cases if ethanol distilleries do not use premium fuels in their boilers. Moreover, with either ethanol or methanol, more premium fuel can be saved (up to the energy equivalent of about 0.4 gal of gasoline per gallon of alcohol)' if the alcohol is used as an octane-boosting additive to gasoline, rather than solely for its fuel value (e. g., as in most onfarm uses). This additional savings occurs because it requires less energy for most oil refiners to produce a lower octane gasoline.

Therefore, **saving the maximum amount of premium fuel in ethanol production requires: 1) that ethanol distilleries not use premium fuels in their boilers, and** 2) **that the alcohol be blended with a lower octane gasoline than that which the gasohol will replace rather than being used as a standalone fuel. If these two conditions are met, each gallon of ethanol can save nearly one gallon of premium fuel.** There are, however, unresolved questions about the most economic strategies for using **methanol** fuel to replace oil. The entire liquid fuels system —from refinery through various end uses — needs to be analyzed to develop an optimum strategy.

● See box D on p 38 for a discussion of the uncertainty associated with this estimate

Most cars in the existing automobile fleet probably can run on gasoline-alcohol blends containing up to 10 percent ethanol with only minor changes in mileage and performance. Some automobiles, however, will experience problems– potentially more severe with methanol than with ethanol — such as surging, hesitation, stalling, and possibly fuel tank corrosion. Because new cars are being manufactured to accept ethanol-gasoline blends, the problems with this fuel are likely to disappear with time. With methanol blends, however, the uncertainties are greater. If substantial automotive performance problems do emerge, other additives may have to be included in such blends.

Anaerobic Digestion

Full use of the manure resource for producing biogas will require the development of a variety of small, automatic digesters capable of using a wide range of feedstocks. This is because approximately 75 percent of the animal manure that can be used to produce biogas is located on relatively small, confined animal operations of several different types — chickens, turkeys, cattle on feed, dairy cows, and swine.

The principal cost of anaerobic digestion of manure is the capital cost of the digester system. Therefore, developing less expensive digesters and introducing incentives and financing schemes that lower the investment cost to farmers will greatly improve the prospects for these energy systems.

In addition to its energy potential, anaerobic digestion is valuable as part of a manure disposal technique. The digester effluent also may serve as a protein supplement in animal feed, although its exact value for this purpose has not been established. Either of these possibilities could improve the economics of on-farm digestion significantly.

Potential for Displacement of Oil and Natural Gas

Up to 10 Quads/yr of oil and natural gas could be displaced by wood and herbage by 2000, but the actual displacement achieved with bioenergy systems depends on the conversion processes chosen and the market for the resulting fuels. Gasification and conversion to methanol, in that order, appear to offer the greatest promise. Gasi-fication is the more energy efficient of these conversion technologies, and can serve as a direct substitute for the use of oil and natural gas both for process heat and steam. Methanol can also directly displace petroleum fuels, although the conversion of biomass to methanol is less efficient than gasification or direct combustion.

Economic Considerations

Virtually all forms of biomass suitable for energy can have nonenergy uses as well, and bioenergy production will compete with other uses for the same land base. If care is taken to integrate energy with nonenergy objectives, the estimated energy potential from wood and plant herbage probably can be obtained without severe competition from nonenergy uses of these materials. For example, if wood energy harvests are part of a comprehensive silviculture program, they can actually increase the growth of timber suitable for lumber and paper pulp. Similarly, most processing wastes and animal manure and a limited amount of ethanol from grains and sugar crops can be used for energy without impinging upon other markets. As noted previously, however, obtaining large amounts of energy from cropland can inflate food prices. Indeed, any of the bioenergy sources can eventually result in inflation in related nonenergy sectors if the biomass resource is not managed properly.

Competition between energy and nonenergy uses of biomass as well as other uncertainties can affect reliability of fuel supplies. Wood and plant herbage supplies may be diverted for nonenergy uses (e. g., particle board, cattle feed) that may, at times, have a greater economic value. Adverse weather conditions also can interrupt harvesting or reduce total biomass productivity per acre. In addition, in areas where biomass fuels are just starting to be used, imbalances can arise between quantities produced and consumption needs. Moreover, if any of these factors should cause bioenergy supply problems, high transportation costs or local needs elsewhere may make such problems difficult to solve through regional or national adjustments. Hence, bioenergy systems that use oil or natural gas as backup fuels look particularly attractive.

Of equal importance is the possibility of competition between biomass and other energy sources. Solid biomass generally is most economic for producing process steam or heat in medium-size industrial facilities where conversion equipment is operated continuously. Larger facilities may prefer coal because of its potential economies of scale, while much smaller energy users may prefer the convenience of oil or gas, if they are available.

Finally, because biomass fuels tend to be bulky and have a low fuel value per pound, their transportation costs, relative to other fuels, will be high. These costs and the dispersed nature of the resources may limit the size of bioenergy facilities to those requiring less than 1,000 dry tons of biomass fuel per day (roughly equivalent to the input of a 60-MW electric-generating plant). Therefore, market penetration would be aided by the development of reliable, automatic, and inexpensive smaller conversion systems — especially mass-produced gasifiers-–so that small industrial, residential, and commercial users who are familiar with oil, gas, or electricity can switch to biomass without having to learn new skills or make major changes in their operations.

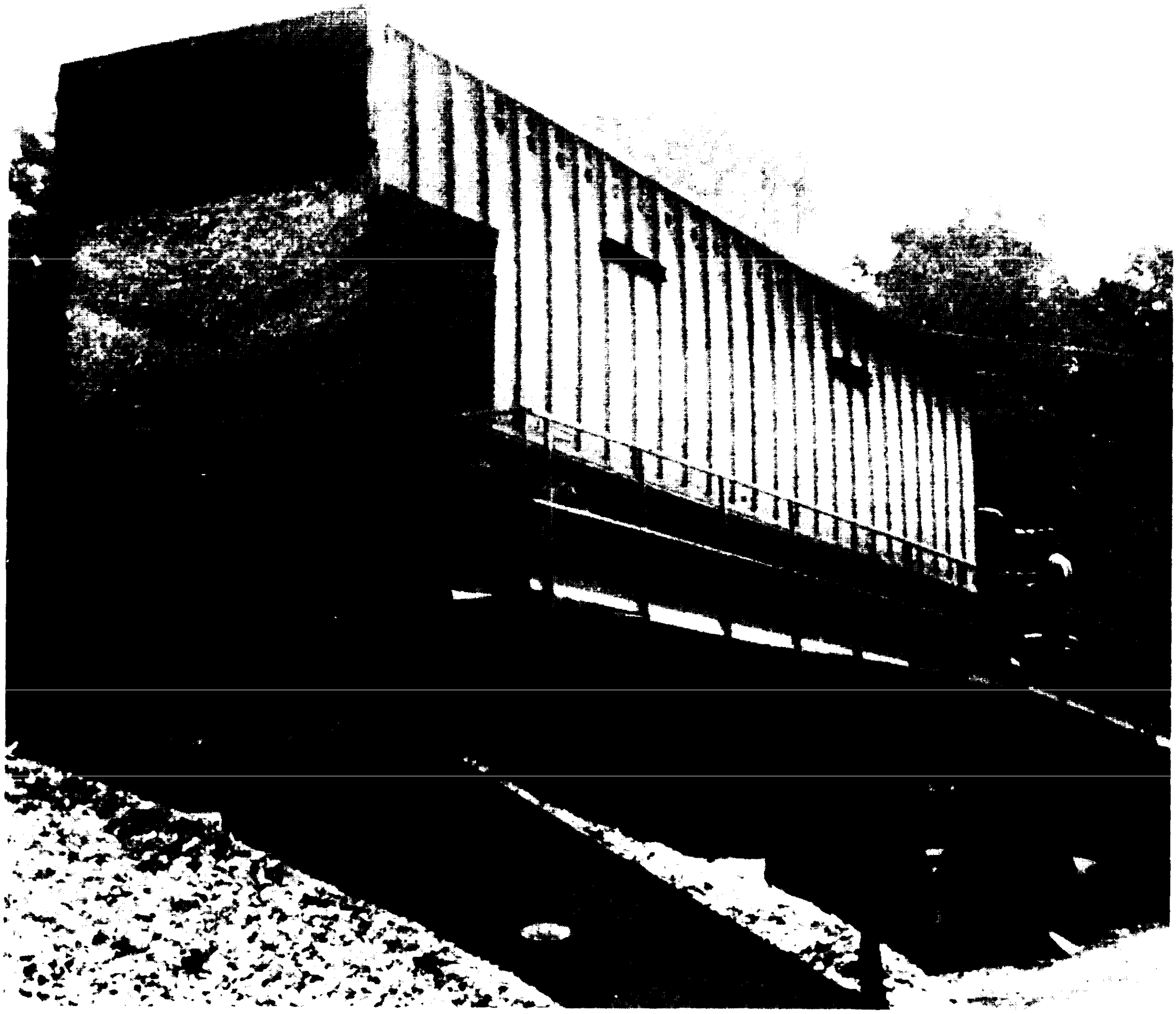


Photo credit USDA—Forest Service

Wood destined for use as fuel often will be chipped at the logging site and transported in vans

Environmental Impacts

Biomass has the potential to be an energy source that has few significant environmental problems and some important environmental benefits. For a number of reasons, however, a vigorous expansion of bioenergy may still cause serious environmental damage because of poorly managed feedstock supplies and inadequately controlled conversion technologies. Also, some uncertainties remain about the long-term effects of intensive biomass harvests on soil productivity.

The major potential environmental benefits of biomass energy development are: the constructive use of wastes that could otherwise cause pollution; the opportunity to improve forest productivity and eventually relieve logging pressure on some environmentally fragile lands; and the displacement of more harmful energy sources, especially coal.

The potential damages from biomass energy development include substantial increases in soil erosion and in sedimentation of rivers and lakes and subsequent damage to land and water resources, adverse changes in or loss of important ecosystems, degradation of esthetic and recreational values, local air and water pollution problems, and occupational hazards, These damages, although not inevitable, appear likely to occur for a number of reasons. First, some of the less intensive agriculture and forestry operations from which biomass supply mechanisms would be derived *already cause* serious pollution problems. Second, biomass feedstock suppliers as well as conversion facilities may be hard to regulate because the choice of appropriate controls and management techniques is very site specific, making it difficult to develop effective and enforceable guidelines for environmental protection. There also are likely to be a great multitude of small sources, thereby creating a significant monitoring and enforcement problem. Third, the existing economic and regulatory incentives for biomass suppliers and users to protect the environment are weak. Finally, some of the currently most popular biomass alternatives — alcohol from grains and wood stoves for residential heating–have a high potential for environmental damage, The major dangers from grain alcohols are the erosion and ecosystem displacement that would be caused by expanding crop acreage to increase production, while large increases in wood stove use may lead to serious public health problems from particulate air pollution.

It also has been suggested that long-term losses in forest or crop productivity will result from declines in soil organic matter associated with residue removal and high-intensity (short rotations, whole-tree harvesting) forest management. However, the degree of these impacts is somewhat speculative at this time.

Alternative biomass feedstocks have sharply different potentials for environmental damage. I n order of increasing potential, they are: 1) wood- and food-processing wastes, animal wastes, and collected logging wastes (no significant potential); 2) grasses (most applications should have few significant adverse impacts); 3) crop and logging residues (some potential for harm if mismanaged, speculative potential for long-term damage to productivity because of loss of soil organic matter); 4) other wood sources (high potential but theoretically can be managed); and 5) grain and sugar crops (highest potential).

Several public policy strategies are available to reduce the environmental problems associated with obtaining and converting these feedstocks. For example, incentives for environmental control may be strengthened by accelerating regulatory programs associated with section 208 of the Clean Water Act for control of nonpoint source pollution, or by directing tax incentives and direct aid to operations practicing proper site selection and management. Some problems with small-scale suppliers and users of biomass might be alleviated by increasing the availability of information and direct technical assistance. In addition, R&D could be accelerated in some key areas, including: 1) design of safe small-scale conversion systems, especially wood stoves and furnaces; 2) determining the environmental effects of certain poorly understood practices and technologies (e. g., whole-tree harvesting); and 3) assessing the effects of various biomass promotional and environmental control strategies.

Social Impacts

Biomass energy development is likely to be more labor intensive than increased production of conventional fuels (coal, natural gas, oil) in the near term. Thus, increases in employment due to bioenergy will occur in resource harvesting (agriculture and forestry); manufacture, distribution, and servicing of conversion equipment (gasifiers, boilers, stills, anaerobic digesters, wood stoves); and the construction and operation of large-scale conversion facilities (generating plants, alcohol fuels plants).

Due to biomass fuel transportation costs, most of these employment increases will arise at small, dispersed rural sites near the resource base. If bioenergy development becomes a major contributor to U.S. energy supplies, the new jobs could alleviate unemployment and underemployment among rural residents— especially in agricultural and forested areas, shift the rural age distribution to a younger population, and help to revitalize rural areas. Agricultural areas, in particular, will benefit from the degree of liquid fuels self-sufficiency afforded by onfarm distillation as well as the overall energy contribution from anaerobic digestion. Moreover, if commercial alcohol fuels production is managed properly, the Nation as a

Photo credit: Herrin F. Culver

An example of controlled silviculture: limited area clearcutting followed by replanting

whole will benefit from the reduced dependence on imported oil. On the other hand, to the extent that bioenergy is subsidized, it will attract investment and jobs at the expense of other sectors.

However, increased bioenergy production also could result in increased rates of accidental injuries and deaths in energy-related occupations. Consequently, safer biomass harvesting and conversion methods need to be developed and implemented. Occupations associated with bioenergy (logging, forestry, agriculture) generally have higher occupational injury rates than do jobs in conventional fossil-fuel sectors (coal mining, oil and gas extraction). In addition, small-scale conversion technologies (wood stoves and onfarm stills) are currently more dangerous than the energy sources they replace.

Finally, **any increased food prices caused by bioenergy production would fall disproportionately on the poor because the purchase of food takes a greater share of their disposable income.** Increased food prices also would raise farmland prices, which could increase economic pressures on small farmers and further concentrate ownership of agricultural land.

Photo credit: USDA—Soil Conservation Service

Mechanized wood harvesting

Policy Considerations

Policymakers can monitor the progress of bioenergy development and its economic, environmental, and other effects carefully, and be prepared to adjust policies as new problems and opportunities emerge. It is especially important for policy makers to take into account the broad range of uncertainty that exists–and will continue to exist for many years — regarding bioenergy conversion technologies themselves as well as the effects of bioenergy feedstock demand on markets for food, feed, materials, and energy.

Therefore, flexibility in Government policy is essential, both to avoid unnecessary costs and to adapt to changing circumstances. A number of mechanisms can be built into bioenergy policies in order to achieve this flexibility, including "sunset" provisions, adjustable price and quantity thresholds for subsidies and incentives, and statutory requirements for the review of existing policies.