Energy From Biological Processes

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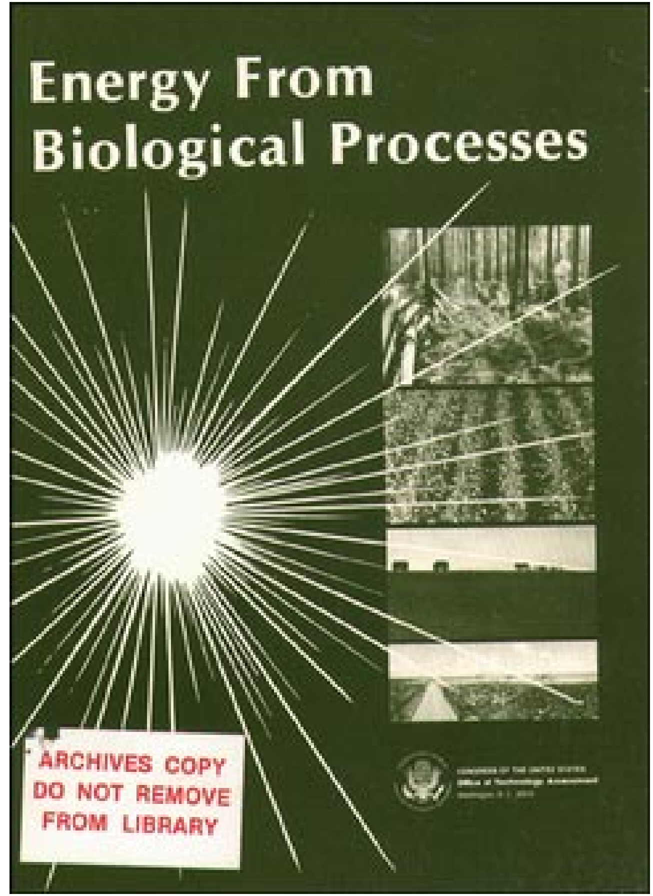

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Foreword

This assessment responds to a request by the Senate Committee on Commerce, Science, and Transportation for an evaluation of the energy potential of various sources of plant and animal matter (biomass). This report complements an earlier OTA report on the *Application of Solar Technology to Today's Energy Needs* in evaluating the major solar energy resources available to the United States. The findings also will serve as part of the material to be used in an upcoming OTA assessment of synthetic fuels for transportation.

This volume presents analyses of prominent biomass issues, summaries of four biomass fuel cycles, a description of biomass' place in two plausible energy futures, and discussions of policy options for promoting energy from biomass. The four fuel cycles —wood, alcohol fuels, grasses and crop residues, and animal wastes —were chosen because of their near- to mid-term energy potential and because of the public interest in them. A second volume presents technical analyses of the resource base, conversion technologies, and end uses that provide a basis for the discussion in this volume. Also included in volume II are various unconventional approaches to bioenergy production as well as the use of biomass to produce chemicals.

We are indebted to the members of the advisory panel and to numerous individuals who have given so extensively of their time and talents in support of this assessment. Also the contributions of several contractors, who performed background analyses, are gratefully acknowledged.

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Overview

Wood, grasses, agricultural crops and their residues, animal wastes, and other sources of biomass currently supply almost 2 percent of U.S. energy consumption (or about 1.5 Quads* /yr), primarily from the use of wood in the forest products industry and in home heating. Depending on a variety of factors, including the availability of cropland, improved crop yields, the development of efficient conversion processes, proper resource management, and the level of policy support, bioenergy could supply as few as 4 to 6 Quads/yr, or as many as 12 to 17 Quads/yr by 2000 (or up to 15 to **20** percent of current U.S. energy consumption). Of the "high development" 12- to 17-Quad range, up to 10 Quads/yr would come from wood, O to 5 Quads/yr from grasses and legume herbage (depending on cropland needs for food production), and 1 Quad/yr from crop residues. In addition, various smaller biomass energy sources could yield approximately 0.5 Quad/yr, including up to 0.3 Quad/yr of biogas from animal manure and about 0.2 Quad/yr of ethanol from grains (approximately 2 billion gal/yr of ethanol or 2 percent of current U.S. gasoline and imported oil consumption).

The bioenergy conversion processes that would be most efficient in displacing large quantities of oil are direct combustion and gasification for process heat and steam and home heat. Combustion technology for wood is commercially available, while suitable gasification units probably can be developed soon. Assuming that market and feedstock supply conditions are favorable, **development and deployment of these technologies could provide the difference of up to 10 Quads/yr between the high and low estimates for bioenergy use in 2000.** This 10 Quads/yr could displace the energy equivalent of 4.5 million barrels per day (bbl/d) of premium fuels (oil and natural gas). It is noteworthy, however, that in most cases, biomass would be competing with coal for these markets.

Liquid fuels are the most versatile form of energy from biomass. Ethanol can be produced from grains and sugar crops with commercial technology. Growing the grains or sugar crops and converting them to ethanol require roughly the same amount of energy as is contained in the ethanol. **A net displacement of premium fuels (oil and natural gas) can be achieved if ethanol distilleries are not fueled with oil or natural gas. This oil displacement can be even more favorable if the ethanol is used as an octane= boosting additive to gasoline rather than solely for its fuel value.**

For the major biomass sources—lignocellulosic materials such as wood, grass, and crop residues—methanol synthesis appears to be the least expensive and nearest term option for producing liquid fuels. Although no facilities to convert biomass to methanol currently exist, a wood-to-methanol plant is being planned, and grass-to-methanol technology probably can be demonstrated more rapidly than economic grass-to-ethanol processes. It is technically possible to displace the energy equivalent of up to 3 million bbl/d of oil in the transportation sector with methanol by 2000. Because of the greater difficulties associated with blending methanol in gasoline, however, **the en= tire liquid fuels system from refineries through distribution and various end**

*A Quad equals 1 quadrillion (10^{15}) Btu. It equals the energy of approximately 460,000 bbl/d of oil for 1 year, 50 million tons of coal, or the typical annual energy output of eighteen 1,000-MW powerplants.

uses should be examined to determine the most economic strategies for introducing methanol, especially in the transportation sector.

Both the quantity of biomass that can be obtained on a renewable basis, and the economic, environmental, and other consequences of obtaining it will depend critically on the behavior of growers and harvesters. For example, careless forest management could substantially reduce the amount of wood available for energy and result in severe environmental damage. In addition, production of ethanol from grains and sugar crops and other uses of cropland for energy (except crop residues) can compete with feed and food crop production and thus lead to more rapid inflation in food prices. At the same time, the needed expansion of acreage in intensive crop production, as well as any overuse of crop residues, will add to the already damaging rate of erosion on U.S. cropland.

Both the energy potential of biomass and the problems inherent in achieving that potential raise three main policy issues that Congress might choose to address.

First, vigorous policy support will be necessary if bioenergy use is to reach 12 to 17 Quads/yr by 2000. This support could take the form of economic incentives to accelerate the introduction of bioenergy and to promote the establishment of reliable supply infrastructures.

Second, because of the unresolved questions about the biomass resource base, the way the complex and interconnected markets will respond, and how constraints will change with time, **incentives for bioenergy development should include provisions for periodic review and adjustment.** In the case of grain ethanol, this reevaluation might occur when planned distillery capacity approaches 2 billion gal/yr—the level at which conservative economic calculations indicate that significant food price increases might begin. In the case of wood and other lignocellulosic materials, a formal review of the condition of the forests and soils might be instituted when 5 Quads/yr of these materials are being used for energy.

Third, bioenergy currently remains a low priority in the Departments of Energy and Agriculture— the Federal agencies able to directly influence the speed and direction of development. The aggressive promotion of bioenergy therefore will require a reorientation of Federal program goals, as well as extensive coordination among Federal agencies, and among National, State, and local governments.

Chapter 1

SUMMARY

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Chapter 1
SUMMARY

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

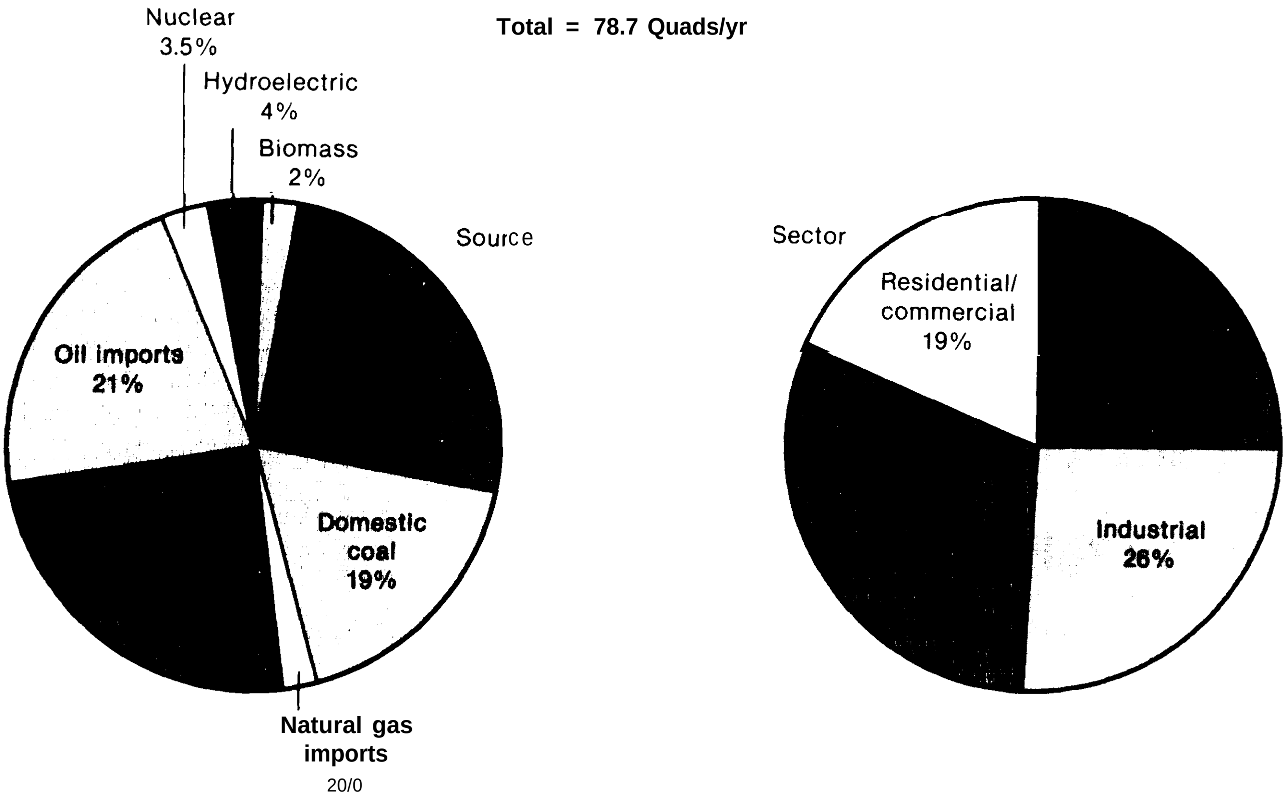
A very substantial amount of energy, as much as 12 to 17 Quads/yr, depending on cropland needs for food production, could be produced from biomass sources in the United States by the year 2000. (Current U.S. energy consumption is **79** Quads/yr (figure 1); oil imports are 7 million bbl/d or about 16 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

Total = 78.7 Quads/yr



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

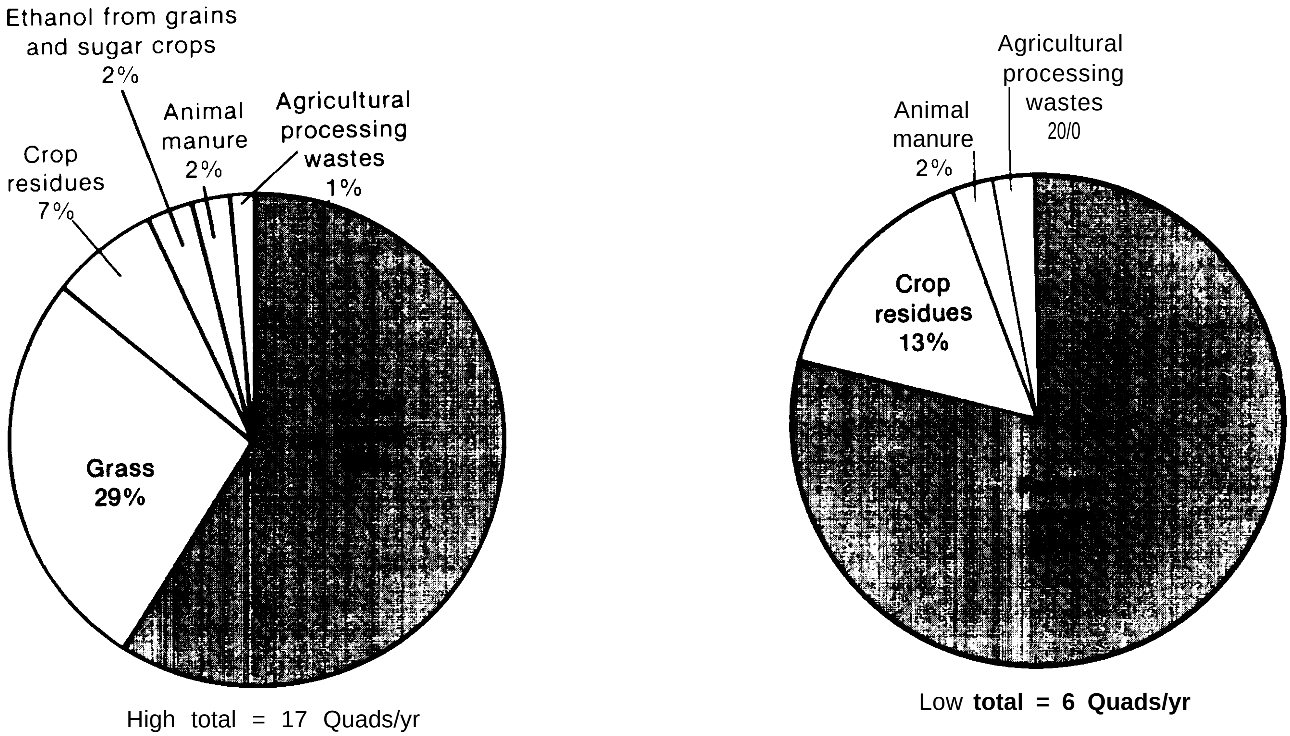
Combustion of wood (including paper-pulping liquor) is the major energy use of biomass today, with about 1.2 to 1.3 Quads used annually for process energy in the forest products industry, and 0.2 to 0.4 Quad/yr in home heating, fireplaces, and other uses (e. g., charcoal grills). Wood combustion, **primarily** 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 (' Ott Ice 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

Commercial forests: an excellent source of energy from biomass

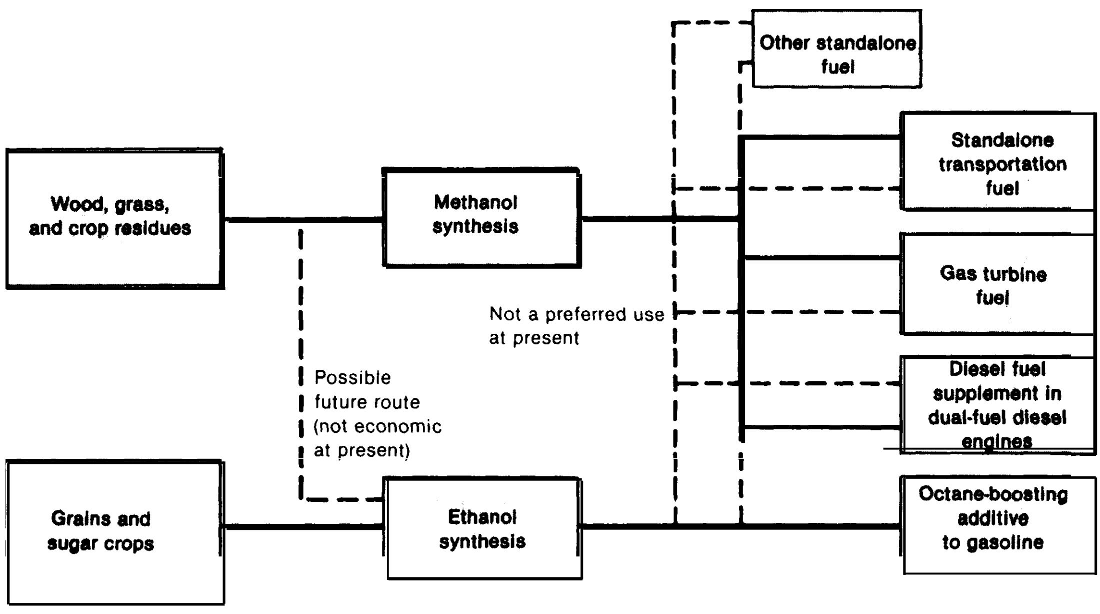
Alcohol Fuels

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 onfarm 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.

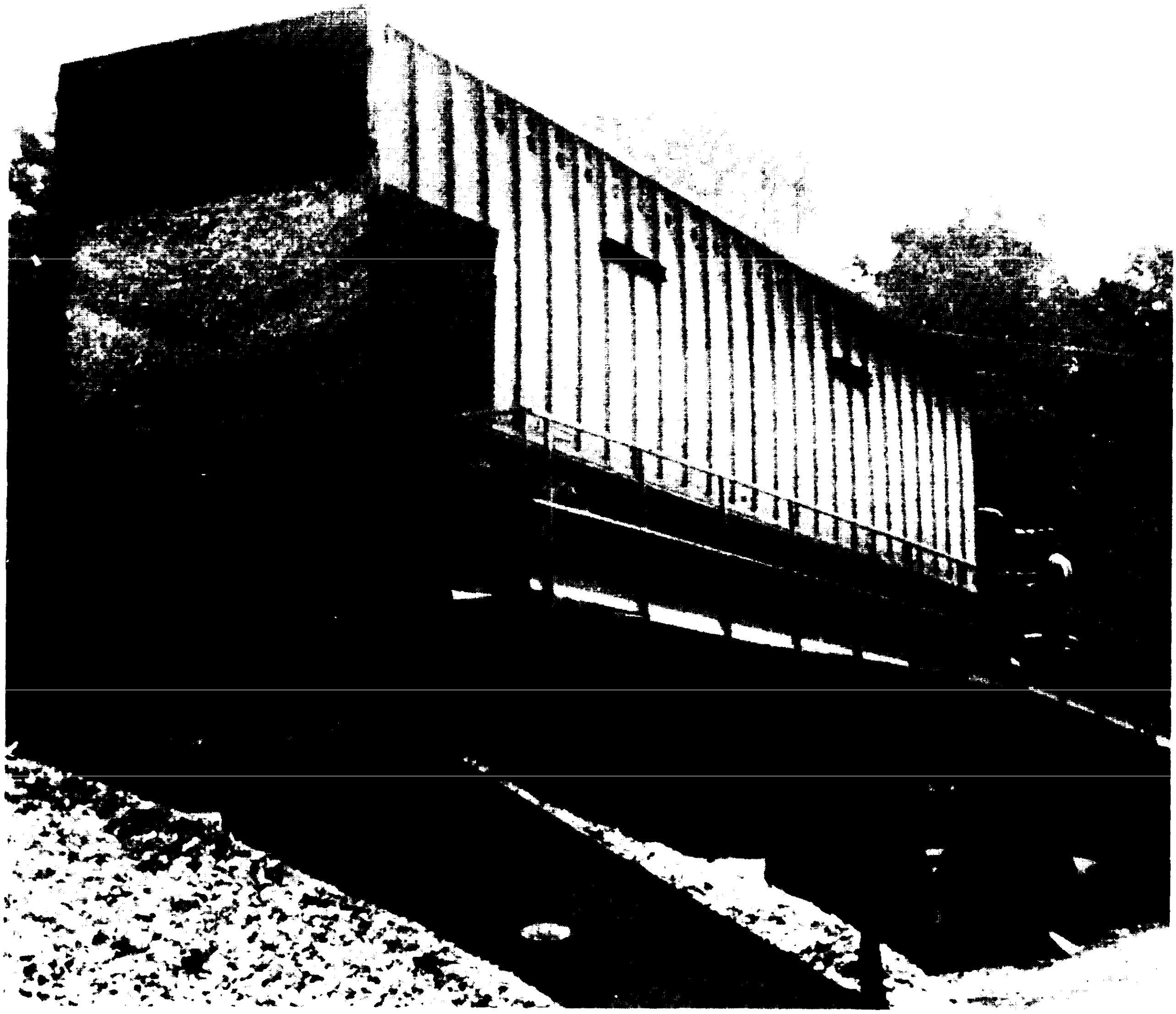


Photo credit USDA—Forest Service

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.

Chapter 2

INTRODUCTION

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TABLE

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INTRODUCTION

In recent years, rapidly rising fuel prices, depleting domestic oil and gas reserves, the deficit in the U.S. balance of trade, and the possibility of political interruption of oil supplies have led to a search for less expensive, more reliable domestic energy sources. In addition, a number of factors, such **as uncertain energy** demand growth, soaring construction costs, difficulty in plant siting, and the environmental problems associated with coal, have led some energy producers and consumers to question the appropriateness of the large centralized energy systems that have been developed over the last 30 years.

All these concerns have focused attention on energy from biological processes, or biomass—primarily energy uses of plant material and of municipal, industrial, and animal wastes. Biomass represents a renewable domestic source of liquid and solid fuels that can be used in relatively small decentralized energy systems. In addition, if biomass resources and conversion processes are managed properly, they have a much lower potential for environmental damage than coal and coal-based synfuels.

This report analyzes the potential of biological processes as a renewable domestic source of solid, liquid, and gaseous fuels and chemical feedstocks. The report assesses the bioenergy resource base, conversion technologies, and end uses; analyzes the environmental and social impacts that could accompany the widespread use of bioenergy; and identifies policy options that would promote commercialization and proper resource management. In addition, the report highlights research and development needs and bioenergy's potential for displacing premium fuels.

Because of the large number of biomass fuel cycles (one recent study identifies more than 1,000 such cycles), not all of them could be analyzed in this report. Rather, a detailed analysis is presented of four fuel cycles that are likely to contribute significant amounts of energy within the next 20 years, will contribute to energy self-sufficiency within a particular economic sector, or will provide a source of liquid fuels. These four fuel cycles are: 1) wood for gasification, alcohol fuels production, and direct combustion; *2)* grain and sugar crops for alcohol fuels production; *3)* grass and legume herbage and crop residues for combustion or alcohol fuels production; and 4) animal manure for anaerobic digestion (biogas). (A fifth fuel that could contribute substantial amounts of energy — municipal solid waste— is analyzed in another OTA report and is not discussed here.)

Volume I of this report is organized as follows:

- chapter 3 highlights the central issues surrounding bioenergy and summarizes OTA's findings on those issues;
- chapter 4 presents an overview of the four fuel cycles, including their technical features, economics, environmental impacts, and social implications, and their potential to displace conventional fuels; and
- chapter 5 analyzes policy options that would encourage the introduction of the four fuel cycles into U.S. energy supplies.

Contents of Volume II

Volume II presents a detailed analysis of the technical features of the four fuel cycles as well as other forms of bioenergy; these include the resource base, conversion technologies, and end use. The subjects covered in volume II include:

Resource Base

- **Forestry:** estimates of the standing timber inventory, current harvests, potential growth, harvesting costs, factors affecting wood availability, practical energy potential, environmental impacts, and research, development, and demonstration (RD&D) needs.
- **Agriculture:** estimates of plant growth and crop yields, cropland availability, current

farming practices and yields, energy potential including crop switching, crop residues, environmental impacts, and RD&D needs.
- **Unconventional biomass approaches:** discussions of genetics, crop yields, unconventional land-based crops (lignocellulose, starch and sugar, and oil and hydrocarbon crops), aquiculture (freshwater plants), mariculture (ocean water crops), and other unconventional approaches including multiple cropping, chemical inoculation, energy farms, biophotolysis, inducing nitrogen fixation in plants, and greenhouse cultivation.
- **Biomass wastes:** analyses of the byproducts of biomass processing that are suitable for energy, including forest products industry byproducts, agricultural product processing wastes, and manure.

Conversion Technologies and End Use

- **Thermochemical conversion:** discussions of general aspects, reactor types, optimum size, biomass densification, direct combustion, gasification, liquid fuels synthesis (including methanol, pyrolytic oil, and ethanol), environmental impacts, and RD&D needs.
- **Fermentation:** analysis of ethanol from starch and sugar crops including energy use, process byproducts, costs, and onfarm distillation; discussion of cellulosic feedstocks including general aspects, processes under development, and plausible future costs; environmental impacts; and process innovations.
- **Anaerobic digestion:** analysis of general aspects, reactor types, costs, environmental impacts, and RD&D needs.
- **Use of alcohol fuels:** discussion of spark ignition engines using gasohol, straight ethanol, methanol-gasoline blends, and straight methanol; diesel engines; gas turbines; and environmental impacts.
- **Energy balances for alcohol fuels:** analysis of energy use in producing ethanol from grains and sugar crops, methanol from wood and plant herbage, and general considerations.
- **Chemicals from biomass:** a brief description of various possibilities for chemicals synthesized by plants and chemical synthesis from wood and plant herbage.

Throughout this report, an effort was made to use consistent units of measure but this was not always possible. Consequently, table 1 presents the conversion factors between various common units of measure. It should be kept in mind that in some cases the conversion is only approximate because no exact equivalence exists (e. g., between cubic feet and dry tons of wood).

Table 1.—Select Conversion Factors

Wood	
1 cord wood	= 1 dry ton
1 green ton (50% moisture)	= 0.5 dry ton (50% moisture)[a]
1 dry ton (50% moisture)	= 16 million Btu
1 dry ton (0% moisture)	= 18 million Btu
1 ft^3 wood	= 34 dry lb (solid)
	= 11 dry lb (chips)
Grass	
1 dry ton grass	= 13 million Btu
Grain and sugar	
1 bu corn	= 56 lb
1 bu wheat	= 60 lb
1 bu barley	= 40 lb
1 bu oats	= 32 lb
1 bu grain sorghum	= 56 lb
1 ton (fresh) sugarcane	= 0.1 ton sugar
Ethanol	
1 ton sugar	yields 137 gal ethanol
1 ton grain	yields 93 gal ethanol
1 ton wood	yields 70-120 gal ethanol (estimated)
1 ton grass	yields 70-120 gal ethanol (estimated)
1 gal ethanol	= 84,300 Btu (higher heat)
	= 76,200 Btu (lower heat)
Methanol	
1 ton wood	yields 120 gal methanol
1 ton grass	yields 100 gal methanol (estimated)
1 gal methanol	– 63,500 Btu (higher heat)
	= 55,700 Btu (lower heat)
oil	
1 gal gasoline	= 125,000 Btu (higher heat)
	= 117,000 Btu (lower heat)
1 bbl crude oil	= 5.9 million Btu
Energy	
1 million Btu	= 1 million Btu
1 Btu	= 1,055 joule
1 watt	= 1 joule/see
1 kWh	= 3.6 million joules
1 kWh	= about 10,000 Btu (net heat input, no cogeneration)
1 kWh	= about 3,500 Btu (heat input with cogeneration)
1 Quad/yr	= 464,000 bbl/d of oil
1 million bbl/d of oil	= 2.15 Quads/yr
Land use	
1,000 dry ton/d of wood (enough for 60-MWe generation) can be obtained as a steady Yield from	180,000-360,000 acres of average forest land as now managed
	90,000-180,000 acres of more intensively managed average forest land
A net premium fuel displacement of 1,000 gal/yr of gasoline can be achieved from	‘About 1.4 acres of new cropland put into production with corn, distillery fueled with coal, byproducts used fully to replace soybean production and increase corn production further, and ethanol used as octane-boosting additive to gasoline[b]
	About 2.7 acres grown in grass converted to methanol or ethanol used as an octane-boosting additive to gasoline
	About 3.3 acres of new cropland grown with corn, distillery fueled with coal, byproducts used fully to replace soybean production and increase corn product ion further, ethanol used as standalone fuel.
	About 6.4 acres grown in grass converted to methanol or ethanol used as standalone fuel
	About 7.4 acres grown with corn, distillery fueled with coal, no byproduct utilization, ethanol used as octane-boosting additive to gasoline.
	About 25 acres grown with corn distillery fueled with coal, no byproduct utilization, ethanol used as standalone fuel.
	About 330 acres in grain sorghum, distillery fueled with coal, ethanol used as standalone fuel.
	Infinite acres grown in corn or other grain if oil used as distillery boiler fuel and ethanol used as standalone fuel.
Photosynthetic efficiency	
Average U.S. forest as now managed	0.07 to 0.1 50/0
Average U.S. forest under intensive management	0.15 to 0.370
Average U.S. corn (108 bu/acre, 1979)	0.9°/0 during growing season 0.5% averaged over entire year
Record corn yield in United States (340 bu/acre)	3.0% during growing season 1.5% averaged over entire year
Other solar efficiencies	
Array of photovoltaic cells	10 to 12%
Flat plate collector	30 to 40%

[a] Dry ton refers to the weight of wood (less the moisture). Thus, 1 dry ton (50% moisture) contains 1 ton of wood plus 1 ton of water thereby weighing 2 tons One green ton (50% moisture) weighs 1 ton

[b] The energy savings at the refinery attributed t. ethanol's octane.boosting ability is an Important variable in this calculation OTA estimates. based on the available evidence. that the energy equivalent of O 4 gal of gasoline can be saved for each gallon of ethanol used as an octane. boosting additive If the actual savings are less than this, then the acreages required to save 1 000 gal/yr of gaoline will Increase See box D for a discussion of the uncertainty associated with the estimate of the energy saving

SOURCE Off Ice of Technology Assessment

Chapter 3

ISSUES AND FINDINGS

Chapter 3.—ISSUES AND FINDINGS

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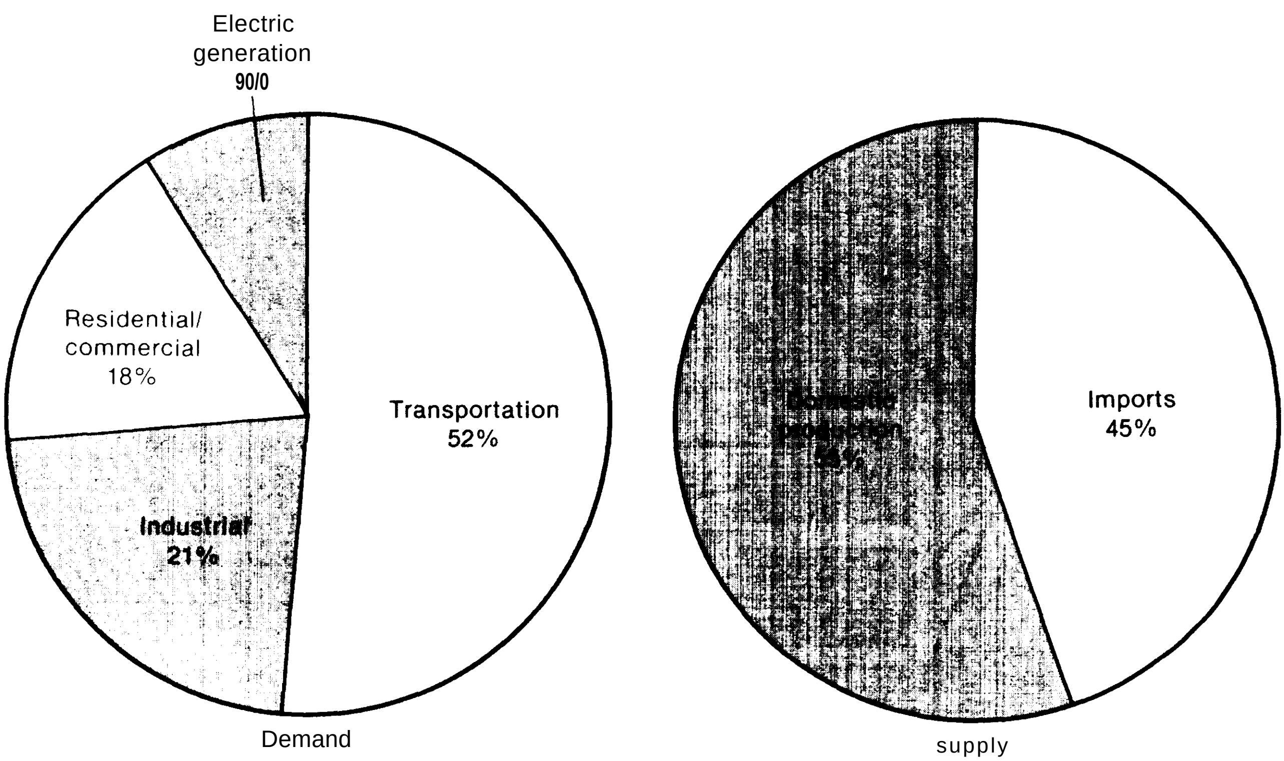
ISSUES AND FINDINGS

How Much Energy Can the United States Get From Biomass?

As much as 17 quadrillion Btu (Quads) per year could be produced from biomass sources by 2000. Seventeen Quads/yr is the energy equivalent of about 8.5 million bbl/d of oil, and would be over 20 percent of current U.S. energy consumption of **80** Quads/yr (see figure 4). Assuming U.S. energy use climbs to 100 Quads/yr by 2000, biomass could make a substantial contribution to the administration's goal of 20-percent solar at that time.

However, the quantity of biomass that actually will be used for energy is intimately connected to the economics of growing and collecting the biomass materials and converting them to usable energy as well as to the demand for other uses for the biomass and for the land, water, and energy used to grow it. Numerous other factors also will influence bioenergy consumption, including the long-term goals and esthetic preferences of landowners,

Figure 4.– U.S. Oil Consumption in 1979



Total oil consumption = **37** Quads
(45% of total energy consumption)

SOURCE Monthly *Energy Review* Energy Information Administration Department of Energy February 1980 and the environmental effects of obtaining biomass and converting it to energy. If cropland availability is the only limiting factor, up to 12 Quads/yr could be available from bioenergy. However, all of the above factors together could limit bioenergy use to 6 Quads/yr by 2000. The various forms of bioenergy (see figure 5) and their potential contributions to this 6 to 17 Quads— assuming the demand is there— are shown in table 2 and discussed briefly below.

Wood From Commercial Forestland

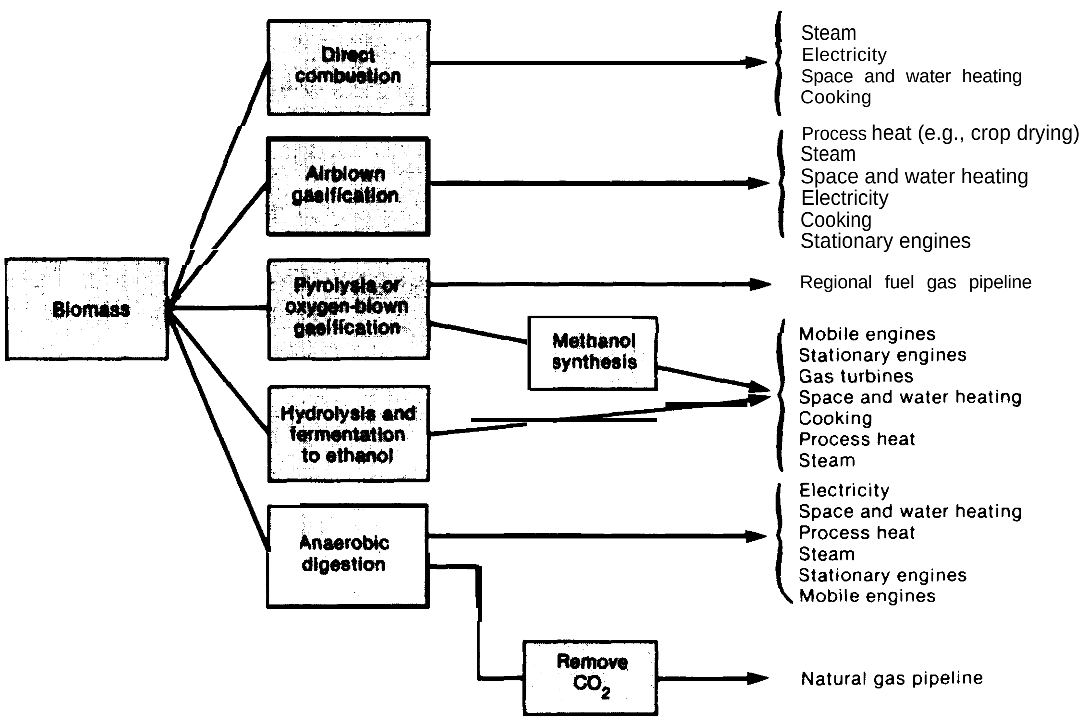
Wood from commercial forestland* is the largest potential source of bioenergy. Most of this could be obtained from the byproducts of wood processing, such as sawdust and spent paper-pulping liquor, and from the byproducts of increased forest management practices, such as collecting logging residues, converting stands (via clearcutting and replanting) to trees with a higher market value, thinning stands to enhance the growth of the remaining trees, and other management techniques. At least 4 Quads/yr of energy probably will be produced from wood by 2000 with little or no Government action, and as much as 10 Quads/yr could be produced with appropriate incentives and forest management practices.

Grass and Legume Herbage

Another source of bioenergy is increased grass and legume herbage production on existing hayland and on both cropland and noncropland pasture. Production could be increased by applying fertilizers and managing the crops to maximize energy production. By 2000, some of the more level grasslands will be converted to row and close-grown crops (such

'Commercial forestland is defined as forestland that is at least 10 percent stocked with forest trees or has been in the recent past, has not been permanently converted to other uses, and is capable of producing (although it may not be currently) at least 20 ft ³/acre-yr of commercial timber Parks and wilderness areas are not commercial forest land, but many privately owned woodlots are

Figure 5.—Fuel Uses for Biomass



SOURCE Office of Technology Assessment

Table 2.—Gross' Energy Potential From Biomass Assuming Maximum Rate of Development
(does not include projected demand)

Source	Biomass	Gross energy potential' (Quad/yr) 1979	1985	2000
Commercial forestland (includes mill wastes)	Wood	1.4- 1.7	3-5	5-10
Hayland, crop land pasture, and noncropland pasture	Grass and legume herbage	0	1-3	0 - 5[b]
Cropland used for intensive agriculture	Crop residues	0	0.7-1	0.8- 1.2
(Grain and sugar crop option)	Ethanol (from grains and sugar crops)	0.004 (50 million gal/yr)	0.08- 0.2[b] (l-3 billion gal/yr)	0 - 1[b] (0-12 billion gal/yr)
(Grass or short-rotation tree option)	**Grass** or short-rotation trees[c]	0	0.3- 1.6[b]	0 . 5[b]
Manure from confined animal operations	Biogas (for heat and electricity)	Less than 0.001	0.1	0.1 -0.3
Agricultural product processing wastes		0.01	0.1	0.1
Other		Less than 0.1	Less than 0.1	Unknown
Total		1.4- 1.7	5.3-11	6- 17[d]

aDoes not Include deductions for cultivatlon and harvest energy, losses, or end-use efficiency
bThese Categories are not additive because they use some of the same land
cAssuming 4-ton/acre-yr yield in 1985 and 6-ton/acre-yr in 2000.
dUpper limits in 2000 for wood, grass and legume herbage, crop residues, and biogas In addition, about 2 billion gal/yr of ethanol are assumed to be produced from grains and sugar crops

SOURCE Off Ice of Technology Assessment

Photo credit USDA —Soil *Conservation Service*

The fuel value of wood harvested during thinning operations is an added incentive for intensified forest management as corn and wheat) to supply food and feed requirements, reducing the amount of land that could be available to grow grass and legume herbage for energy. On the other hand, if the demand for food and feed is less than anticipated relative to the available cropland and some of the land in herbage production is replanted with fast-growing grass, legume, or tree hybrids, the bioenergy potential of this land could increase. There is, however, no assurance that cropland will be available for energy uses in 2000, and attempting to obtain energy from cropland (other than from crop residues) could lead to inflation in food prices in the long term.

Crop Residues

About 20 percent of the material left in the field after grain, rice, and sugarcane harvests (crop residues) could be a source of bioenergy. (The other 80 percent of crop residues is needed to protect the soil from erosion or would be lost during harvest or storage.) For an average crop yield, about 1 Quad/yr of crop residues could be collected and used for energy without exceeding current soil erosion standards. Local variations in crop yields, however, might limit the reliable and usable supply to about 0.7 Quad/yr. This supply is likely to increase in rough proportion to increases in crop production.

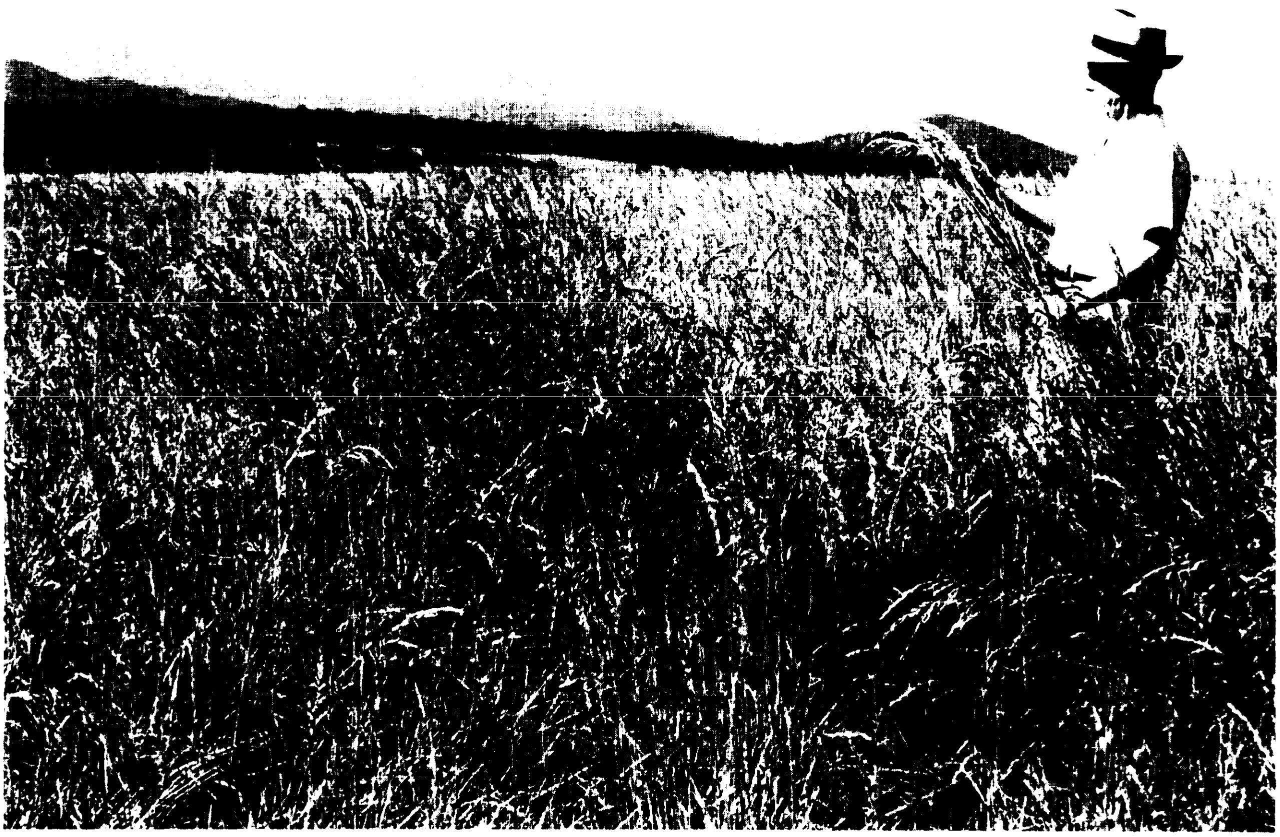


Photo credit USDA, *David Brill*

High-yield grasses could be a significant source of bioenergy

Ethanol Feedstocks

The principal limit on energy uses of grains and sugar crops is the potential for farm commodity price increases as energy crop use rises and the amount of inflation in food prices that is acceptable for energy production (see box A). It is likely that at least 1 billion gal/yr of ethanol from grains and sugar crops —or enough to displace approximately 60,000 bbl/d of gasoline or about 0.8 percent of current gasoline consumption — can be produced without inflationary impacts in the farm sector. Conservative economic calculations indicate that farm commodity price rises could begin to be significant at the 2-billion-gal/yr level. * Depending on the actual response in the agricultural sector–the amount of new land brought into production, the degree to which grains can be bought in export markets, and the amount of crop switching** that is practical — it may be possible to obtain still more ethanol without excessive inflation.

A production capacity of slightly more than 3 billion gal/yr might be achieved by mid-1985 if construction starts on 20 new 50-million-gal/yr distilleries during each of the years 1981, 1982, and 1983. This production capacity could displace about 1.5 to 2.5 percent of current gasoline use. However, if significant farm commodity price increases resulted, they would limit growth in capacity.

Beyond 1985, the land available for intensive production of energy crops could either increase or decrease, depending on future demand for food, the average yields achieved, and the food price rises needed to induce farmers to bring new land into production. There are, however, plausible scenarios in which no surplus cropland capable of supporting row and close-grown crops will be available for energy feedstock production by 2000.

*See "Alcohol Fuels" in ch 5 and app B

**The most productive crop for ethanol production that is being grown on large areas of U S cropland is corn Because the byproduct of producing ethanol from corn can be substituted to a certain extent for soybean production, the inflationary impacts of cropland expansion are reduced as long as the byproduct is fully utilized (see box A)

To the extent that cropland is available for intensive energy crop production, greater quantities of liquid fuel can sometimes be obtained per new acre cultivated and with more benign environmental impacts by planting fast-growing grasses, legumes, or short-rotation trees (lignocellulose crops) rather than grains or sugar crops (see "What is the Potential of Biomass for Displacing Conventional Fuels?"). The approximate quantities of biomass available with this option also are shown in table 2.

Manure

About 0.3 Quad/yr of biogas (methane-carbon dioxide gas mixture) could be produced by anaerobic digestion of the manure from confined livestock operations. Much of this biogas would be used for heat or to generate electricity for use onfarm and for sales to electric utilities. The economics of producing the biogas, however, may limit its energy potential to less than 0.1 Quad by 1985. Improvements in digester technology could reduce the costs so that much of the manure could be used for energy by 2000.

Agricultural Product Processing Wastes

The majority of byproducts from the food-processing industry already are used for animal feed, chemical production, or other nonenergy uses. About 0.1 Quad/yr, including sugarcane bagasse, orchard prunings, cheese whey, and cotton gin trash, either are being used (e. g., some sugarcane bagasse and cheese whey) or could be available for energy.

Other Sources

Energy also can be obtained from various unconventional types of biomass, such as oil-bearing plants, arid land crops, native rangeland plants, and both freshwater and saltwater aquatic plants. Many unconventional crops would have to be grown on land suitable for traditional crop production and their potential would be limited partly by the availability of this land. The arid land crops, however, could be cultivated on cropland where there is slightly less rainfall or irrigation water than is needed to cultivate traditional crops successfully. Freshwater plants might be cultivated in

Box A.—What Effects Could Ethanol Production Have on Food Supplies and Prices?

Grain and sugar feedstocks for ethanol also have food and feed value and buyers in these three markets will bid against each other for farm commodities. As ethanol production increases, distillers will have to pay higher prices to induce adjustments in the allocation of agricultural resources in order to increase their share in these markets. Five likely market adjustments are described below.

First, higher feedstock prices make it profitable for farmers to bring new cropland into production. Approximately 5 million to 7 million acres of medium-quality cropland are needed to produce a billion gallons of ethanol (not including increased yields due to crop and feed substitutions; see "What Is the Potential of Biomass for Displacing Conventional Fuels?"). End-use subsidies, such as the Federal excise tax exemption, and rising demand for gasohol will bring some additional high- or medium-quality cropland into production, but higher feedstock prices will be needed to make crop production on this land more profitable than current uses, such as pasture and recreation, and to compensate for the higher cost and risk of farming this land.

Second, higher prices for grains and sugar crops make it profitable for farmers to substitute these crops for those currently produced and change livestock rations. For example, farmers could plant corn and alfalfa instead of soybeans and use distillers' grain and forage as feed in lieu of whole corn and soybean meal. Although soybean land often is not suited to corn, and distillers' grain is not a perfect substitute for soybean meal, more crop switching will occur as corn prices increase relative to soybeans.

Third, higher commodity prices may reduce export demand, and thus increase the supply of grain available to distilleries. However, foreign demand has been rising rapidly and also could contribute to higher prices. In addition, if distillers' grain is not exported at prices comparable to whole grain or soybean products, distilling grain into ethanol rather than exporting it may increase the U.S. balance-of-trade deficit.

Fourth, higher prices would reduce the purchasing power of domestic consumers. Although *conservative* estimates indicate that 1 billion to 2 billion gal/yr of ethanol could be produced from grains and sugar crops without resulting in significant food price inflation, food-fuel competition caused by higher production levels could cost consumers the equivalent of several dollars in higher food prices per gallon of ethanol.

Finally, higher commodity prices will be needed to increase grain reserves in order to provide a buffer against short-term supply fluctuations. Such a buffer would reduce the chance that distillery supplies may be diverted to food or feed markets in bad crop years, and it could moderate price fluctuations. Even if other U.S. Department of Agriculture (USDA) income support programs are phased out, farmer-held reserve programs will continue to be important. The higher prices needed to maintain these reserves could be paid by distillers, consumers, or taxpayers, depending on how the program is implemented.

If these market adjustments can provide large resource shifts to ethanol for small price changes, then the 1-billion- to 2-billion-gal/yr estimate of the level at which producing ethanol from grains and sugar crops will cause substantial food price increases can be raised. On the other hand, if it takes very large price incentives to divert land from existing uses to ethanol feedstocks, then the indirect costs of ethanol to food consumers could be prohibitively expensive.

channels near existing bodies of water or in basins constructed on land unsuitable for crop production. Saltwater plants such as kelp might be cultivated on large ocean farms built to support the plants near the surface of the water, without competing for land or for food and fiber production. Kelp currently is cultivated off the coast of China, and is harvested from natural kelp beds off the coast of the United States and elsewhere for the production of emulsifiers. Water-based plants appear to have a potential for high yields. * At present, however, technical and economic uncertainties about yields, harvesting and cultivation techniques, and land availability are too great to assess the long-term potential of these bioenergy sources.

Total

The amounts of energy available from the various major biomass sources are not completely additive. The conversion of some forestland (perhaps as much as **30** million acres or 6 percent of the commercial forestland) to cropland and other uses is not likely to have a large effect on the availability of wood energy. Similarly, there is no direct relationship between the energy that can be obtained from animal manure or agricultural product processing wastes and the other categories. * * However, the various cropland categories are interdependent and the quantities of bioenergy that can be available are difficult to predict.

Strong demand for land for intensive agriculture, either for food and feed or for energy, would decrease the quantity of hayland and cropland pasture. On the other hand, increased grain or sugar crop production could increase the quantities of crop residues slightly, although the marginal quality of much of this new cropland would limit the amount of residue that could be removed. Finally, improvements in crop yields could increase the land available for energy production and the amount of energy obtained from this land.

These factors are likely to have only a small influence on the 1985 estimates for bioenergy supply. By 2000, however, the uncertainties are quite large because both future crop yields and demand for food are unknown. Demand for additional cropland in the Eastern United States also could result if irrigation water shortages develop on western croplands. Furthermore, if there is a large shift from corn-fed to grass-fed beef in order to increase the supply of corn for ethanol, then the quantities of grass available for energy would decrease. More cropland would be available by 2000, however, if the conversion of cropland to other uses, such as subdivisions and industrial parks, is halted.[2]

Because of these uncertainties, no truly satisfactory estimate for the upper limit for energy from the agricultural sector can be derived. The higher total for 2000 given in table 2–17 Quads/yr-–has been calculated by assuming first, that the upper limit of 65 million acres of cropland can be used for energy production and that this land is planted with grasses yielding **an average of 6 ton/acre-yr, and** second, that about 2 billion to 3 billion gal/yr of ethanol could be produced by crop substitutions (e. g., corn for soybeans). This would result in about 5.1 Quads/yr of grass, 1.2 Quads/yr of crop residues, and 0.2 to 0.3 Quad/yr of ethanol, bringing the total to about 6.5 Quads/yr from these sources.

[1]*Energy* From Ocean Kelp Farms (Washington, D C Off Ice of Technology Assessment, draft, June 1979), to be published as comm ittee print

*See "Unconventional Crops" in vol II

* 'Price changes for farm commodities, however, can change the demand for and production of the products of con fined anima l operations and thereby influence the energy obtained from anima l wastes

[2]Otto C Doering, "Cropland Availability for Biomass Production," contractor report to OTA, Aug 6, 1979, see also R IDideriksen, et al , "Potential Cropland Study, " U S Department of Agriculture, Soil Conservation Service, Statistical Bulletin No 578, October 1977, and *Environmental Quality The Ninth Annual Report of the Council on Environmental Quality* (Washington, D C Council on Environmental Quality, December 1978), GPO stock No 041-001 -00040-8

What Are the Main Factors Affecting the Reliability of Energy Supply From Biomass?

Increasing reliance on bioenergy means tying energy supply to complex nonenergy markets and to raw materials whose supply and price can be expected to fluctuate with changes in growing conditions. Insofar as the country's overall energy system is concerned, however, the reliability of biomass fuels is likely to become an important issue only when very large amounts enter the supply stream.

In the case of wood, the resource with the greatest energy potential, there may be uncertainty concerning both price and availability of raw materials for energy production, especially for new users of this resource. Within the forest products industry, which is likely to account for much of the expansion to the level of **5** to 10 Quads/yr in the next two decades, a portion of supply often is assured because the material used for energy is a byproduct of ongoing operations. Even when use exceeds the available byproducts, forest products companies are likely to be in a position to secure additional wood from established supply sources.

Outside of this sector, however, supply reliability may pose a greater problem because of competition, often localized, between the forest products industry and other users of wood. This is because in some areas traditional forest products industries may require a large part of the wood being harvested. In those cases, temporary shortages of woodchips would affect the fuelwood users the most, because the forest products industries would bid up the price of chips to satisfy their process requirements and the other wood users would have to absorb most of the temporary shortage. In other areas, where fuel uses for wood dominate, supply **variations would tend to** be less severe.

Experience within the forest products industry indicates that even with a large wood supply infrastructure, there will be seasonal and yearly price and supply variations. Therefore, wood energy appears more attractive to users who can switch to other fuels during temporary shortages and when prices are high, or who are able to make long-term supply arrangements.

For ethanol produced from grains and sugar crops, price and supply are likely to be subject to the same uncertainties that afflict farm commodities in general: weather, pests and disease, international and domestic market conditions, changes in land values. Energy-oriented farm programs and increased fuel or crop buffer stocks may be desirable to assure supply stability and to control energy price fluctuations.

To a lesser extent these uncertainties also may be expected in the case of heavy dependence on grasses and crop residues. Biogas from the digestion of animal wastes is unlikely to play a large enough role in domestic energy supply to cause concern, although it, too, may fluctuate somewhat as a result of changes in livestock population and feeding practices. But agriculture is highly sensitive to energy supply fluctuations, and the reliability of on-farm stills and digesters will be an important factor in commercialization.

In the very long run, one of the advantages of bioenergy is that it is renewable and need never be depleted provided that the land remains dedicated to this use. Poor management, however, may damage the resource base through erosion and deforestation and force an eventual decline in production.

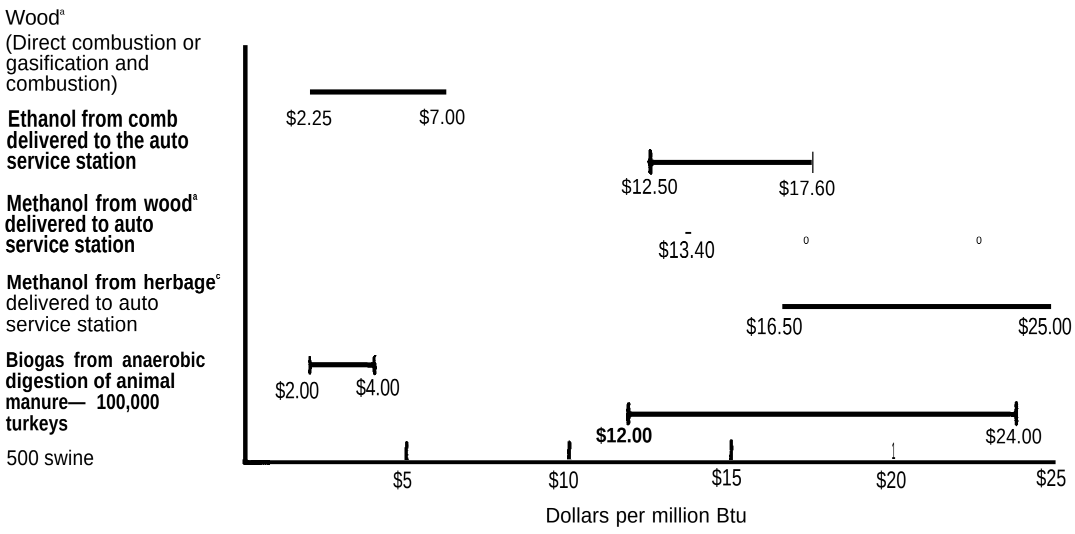
What Are the Economic Costs and Benefits of Biomass Fuels?

Because biomass fuels are relatively bulky and have a low fuel value per pound, their fuel costs (see figure 6) are highly site specific and may pose economic constraints not shared by petroleum or natural gas. For example, these characteristics make the distance between producer and user crucial in calculating total energy costs; as distance increases, total transportation costs rise sharply. These costs and the dispersed nature of the resource base mean that bioenergy users will only have access to a limited number of suppliers and thus will be sensitive to supply fluctuations and price increases.

Bulkiness, perishability, and the solid form of biomass fuels (at least as initially produced) also make costs and benefits for users highly dependent on their skills and their willingness to substitute labor and more complex conversion systems for the familiarity and convenience of conventional liquid and gaseous fuels.

Another major economic obstacle is that users must invest more in equipment and in facilities for storing fuel and disposing of ash. Equipment costs may be reduced in the future with the development of intermediate-Btu gasifiers that can be coupled directly to existing boilers, but users still will have to make larger investments than are necessary for oil or gas. In effect, users will be substituting capital as well as biomass energy for depleting oil and gas resources. As prices for these premium fuels rise, the higher capital costs of biomass substitution can be justified on a lifecycle cost basis, but users and their bankers must take a long-term perspective or the large initial investments will not be profitable.

Figure 6.—Selected Bioenergy Costs
(1980 dollars)



[a]Wood at $30/dry ton.
[b]Corn at $2.50/bu.
[c]Herbage at $45/dry ton.

SOURCE: Office of Technology Assessment

Wood energy economics are by far the most favorable among the biomass options. The fuel value of wood for heating can be derived from the price of #2 fuel oil, which was about $0.90/gal in January 1980. Adjusting conservatively for the higher cost of a wood conversion unit and for its lower conversion efficiency, this oil price corresponds to wood at about $90/dry ton, or approximately twice the 1979 average price of delivered pulpwood. Furthermore, wood fuel users should not have to pay pulpwood prices because fuel-grade timber is generally of lower quality.

Initially, large quantities of fuel can be removed from the current inventory of low-quality trees standing on commercial forestland. However, the key to renewable fuelwood supplies is intensive management of this land once it has been cut over at least once. Intensive silviculture is also critical to the expansion of conventional forest products, because fuelwood and conventional products are economically symbiotic. Revenues from fuelwood sales offset management costs that eventually increase the yield per acre of sawtimber and pulpwood. In turn, expansion of the lumber and pulp industry increases logging residues and mill wastes that can be used as fuel. To take advantage of this two-way relationship, a long-term perspective is required. If landowners make long-term plans, then the resulting improvement in forest product economics could make up to 10 Quads/yr of wood energy available without mining the resource base of standing timber or restricting feedstock supplies for conventional forest products. **But,** if silvicultural practices do not become more in-

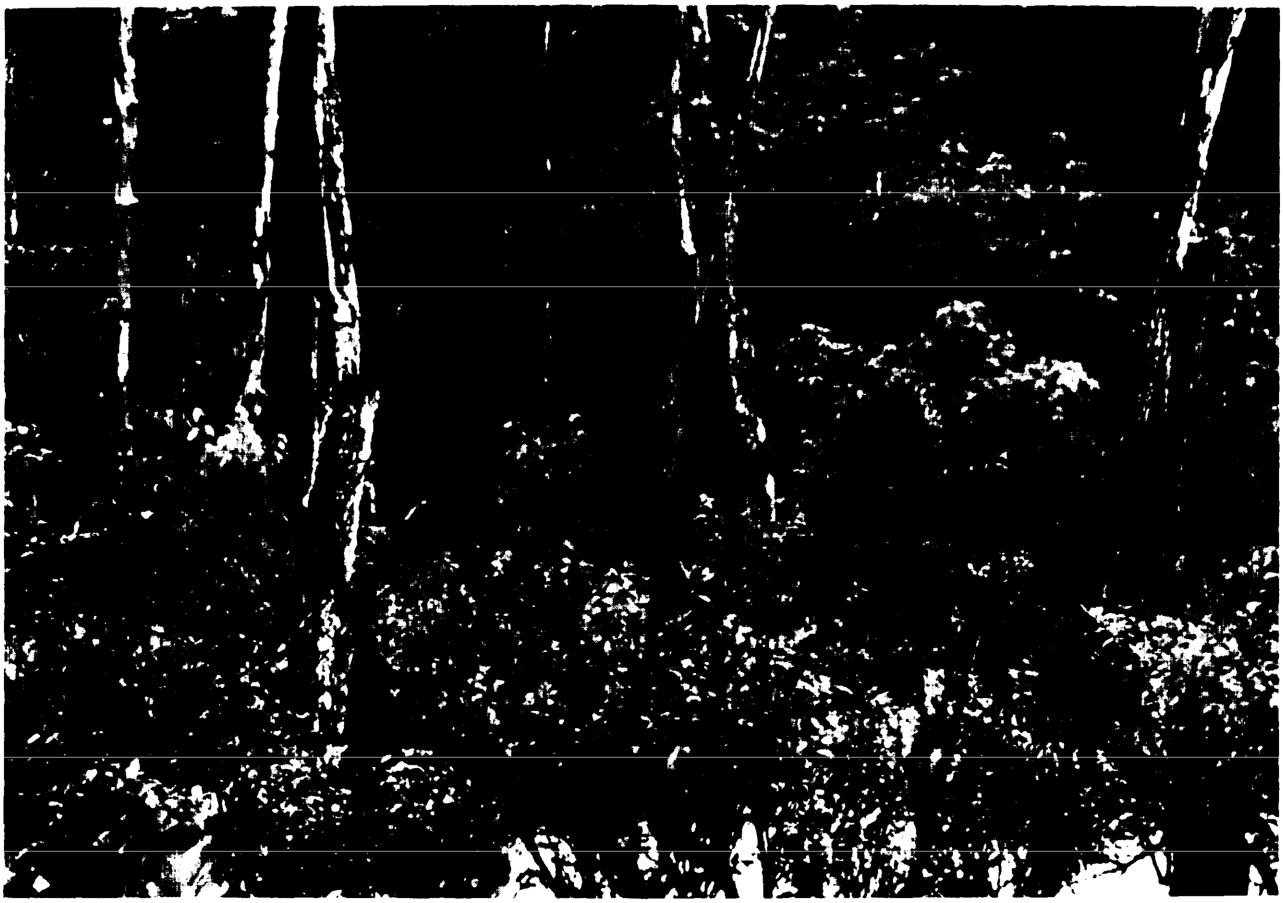


Photo credit Department of Energy

Wood energy harvests, as part of good forest management, can convert forests such as this to commercially productive stands tensive and extensive, removals can outpace new forest growth, and forests may indeed become a nonrenewable resource.

The distillation of **grain ethanol for gasohol** may already be economical, without tax credits, with corn priced at $2.50/bu (or other grains comparably priced) and crude oil at $30/bbl. However, grain prices fluctuate and, partially as a result of greater demand for distillation feedstocks, could rise faster than the price of oil. This uncertainty may discourage investment in new distillation capacity or, once distilleries are built, it may raise the specter of food price inflation as demand for feedstocks competes with demand for feed and food (see box A).

On the other hand, having secure domestic ethanol supplies during the next decade may justify costs per Btu of liquid fuel much greater than the price per Btu of imported oil. * The potentially high cost of ethanol from food and feed crops could be warranted as an insurance premium against import interruptions and because ethanol displacement of imports may slow the rate of growth of OPEC oil prices. While production costs can be estimated on an objective basis, judgments are unavoidable regarding the value of import displacement

Virtually no **grasses or crop residues** currently are used for energy even though, along with wood, they offer the greatest resource potential in the long run. Processes for converting these plant materials into methanol, or wood alcohol, must still be demonstrated but a similar process for wood probably is feasible with commercial technology. Estimated total costs are competitive with or somewhat more expensive than ethanol from feed and food crops, and definitely more expensive than methanol from coal. However, methanol from lignocellulose can be produced in much larger quantities than grain ethanol, without driving up prices of other basic commodities, by more intensive management of lower quality pastureland and cropland that may not be needed for food production in the foreseeable future.

Crop residues and lignocellulose crops also can be used in intermediate-Btu gasifiers that are being developed to be coupled to an existing oil- or gas-fired boiler, thus making it unnecessary to replace existing boilers in order to shift away from premium fuels. With this nearly commercial technology, lignocellulose biomass may become competitive over a wide range of medium to small industrial and commercial applications. In addition, gasifiers could be used onfarm for corn drying and for irrigation pumping.

The economics of producing **biogas from manure** through anaerobic digestion are unclear due to limited scientific and technical data. However, it is the only biomass fuel considered that would not compete directly with the production of any other economic commodity. Rather, the byproduct digester effluent may be worth more than the raw manure feedstock and is also less polluting. In either case, biogas' greatest economic value is its contribution to energy self-sufficiency for farmers, enabling them to displace purchased fuels at their retail cost and allowing normal farm operations to continue when conventional fuels are not available.

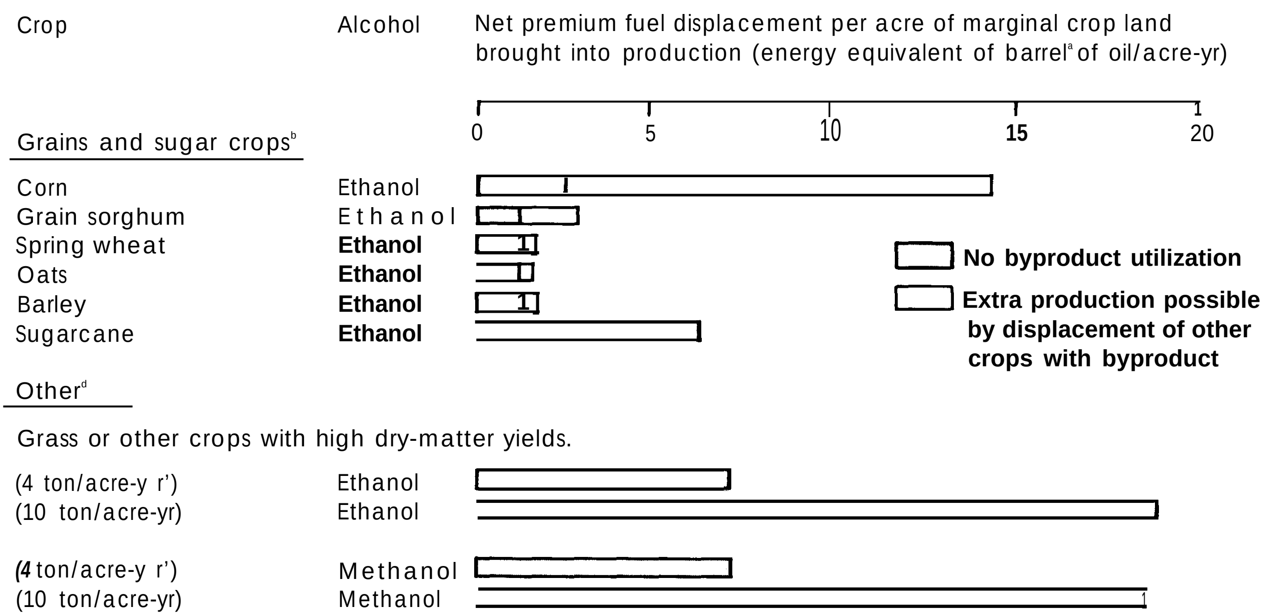
*See Robert Stobaugh and Daniel Yergin, *Energy Futures*, pp 47-55 for a discussion of the real cost as opposed to the market price of imported oil

What Is the Potential of Biomass for Displacing Conventional Fuels?

The three factors that will be most important in determining how much conventional fuel (particularly oil and natural gas) can be displaced by biomass are: how the available cropland is used to produce biomass resources; the way the biomass is converted to useful work, fuel, or heat; and how the converted fuel is used.

Different uses of cropland to produce alcohol fuel feedstocks vary in their efficacy at displacing conventional fuels, depending on the yield per acre of additional cropland brought into production and on the amount of cropland that may be freed by grain distillery byproducts. As can be seen in figure 7, ethanol from corn provides the greatest net premium fuel displacement with current crop yields. This is because it is estimated that each acre brought into corn production would yield enough distillers' grain (DC) byproduct (used as feed) to free almost **0,6** acre of average soybean land for additional corn production. The byproduct from the corn that could be grown on this additional 0.6 acre would free still more land, and so on. When this potential substitution is accounted for, 1 acre of marginal cropland plus about **2.5** acres of average cropland cultivated in corn is equivalent, in terms of animal feed protein concentrate production, to **2.5** acres of average cropland planted in soybeans. Moreover, the ethanol produced from

Figure 7.— Net Displacement of Premium Fuel (oil and natural gas) per Acre of New Cropland Brought Into Production



[a]Based o, 59 million Btu/bbl, alcohol used as octane-boosting additive to gasoline
[b]Assumes national average energy inputs per acre cultivated and yields (on the marginal cropland) of 75% of the national average yields between 1974-77 Yields on average cropland are assumed to be the average of 1974.77 national averages This methodology is Internally consistent, raising the average cropland yield to 1979 yields would not significantly change the relative results If usable crop residues are converted to ethanol, the lower value (no distillery byproduct utilization) would be Increased by about 1 2 bbl/acre-yr or less for the grains and 26 bbl/acre-yr or less for sugarcane
[c]Economic and physical opportunities for full byproduct utilization diminish with greater quantities Of byproduct Production
[d]uncertainty of ±30% for methanol and more for ethanol from grass, since the ethanol processes are not well defined at present Assumes 1 million Btu/dry ton of grass needed for cult ivation, harvest, and transport of the grass, and conversion process yields (after all process steam requirements are satisfied with waste heat or part of the feedstock) of 84 gal/dry ton of grass for ethanol and 100 gal/dry ton of grass of methanol
[e]Four ton/acre-yr can be achieved with current grass varieties grown on marginal cropland

SOURCE. Office of Technology Assessment, yields from USDA, *Agricultural Statistics,* 1978 the corn could have a net annual premium fuels displacement of the energy equivalent of nearly 15 bbl of oil per acre of marginal cropland brought into production, if the ethanol is used as an octane-boosting additive i n gasohol. Other grain and sugar crops have lower yields per acre or an uncertain byproduct credit and thus would displace substantially less premium fuel,

In practice, however, several factors will limit the potential premium fuel displacement per new acre for corn. First, as ethanol production increases the price of corn is expected to rise and distillery feedstock and animal feed buyers will shift to other grains until their prices equalize with corn. Second, as the proportion of DC (or similar gluten byproduct) in animal feed increases, its value as a soybean meal substitute declines. Finally, much of the potential croplands are poorly suited to corn.

Thus, as the fuel alcohol industry is developing, the best energy use of medium-quality cropland brought into production is to grow corn and use the byproducts fully. But as ethanol production increases and the potential for crop substitution decreases, cultivating grasses or other crops with high dry matter yields will become more effective in displacing conventional fuels. As shown in figure 7, these crops already have a greater displacement potential than corn when the DC byproduct is not used. With improved grass yields per acre, their displacement potential could be greater regardless of whether or not the byproduct is used as a soybean substitute. Nevertheless, other crop-switching schemes may be possible and they warrant further investigation.

The second factor that will be important in determining how much conventional fuel biomass can displace is the choice of conversion processes. As discussed previously, wood, grasses, crop residues, and other lignocellulosic materials represent the greatest quantities of biomass available in the near to midterm. The three processes for using these feedstocks are direct combustion, gasification, and liquefaction to alcohol (methanol or ethanol). Gasification and direct combustion are the most energy-efficient processes and liquid fuels production the least, but taking advantage of the octane-boosting properties of alcohols in gasoline blends can make the options more comparable. *

Of the three converted energy forms the most versatile is alcohol while the least is direct combustion. Alcohol fuels can be used in the transportation sector as well as for all the stationary fuel uses for which one can use synthetic gas from biomass (see box B for a comparison of ethanol and methanol as liquid fuels from biomass). Used as a standalone fuel, 10 Quads/yr of biomass converted to the alcohols technically may be able to displace almost 5 Quads/yr (equivalent to about 2.5 million bbl/d of fuel oil) of oil and natural gas by 2000. As an octane booster in gasoline-alcohol blends, alcohol has a higher net displacement (see boxes C and D), but that displacement is limited because the increased savings decreases with blends having a higher alcohol content. I n addition, alcohol-fueled automobiles could be 20-percent more efficient than their gasoline counterparts. Taking these factors into account would result in a displacement of about 3 million bbl/d of oil in the transportation sector. * *

Direct combustion is limited by existing technology to applications such as boilers and space and water heating. Policy and economics already are acting to remove premium fuels from the large boiler market in favor of coal or electricity Therefore, combustion of solid biomass will join coal and direct solar in competing for displacement of oil and natural gas. If used primarily in the residential/commercial sector, it may be technically possible for direct combustion of biomass to substitute for as much as 9 Quads/yr of oil and natural gas (equivalent to about 4.5 million bbl/d of oil) by 2000.

Gasification may provide the largest potential for displacement even though it is limited to stationary sources. This is because it can be used for applications, such as process heat, for which solid fuels are not practical and which, therefore, would otherwise continue to need oil or natural gas. These uses, plus space and

*See "Energy Balances for Alcohol Fuel" in VOl I I

* *See the discussion on fuel displacement at the end of ch 4

Box B.--How Do Ethanol and Methanol Compare as Liquid Fuels From Biomass?

Ethanol from grains and sugar crops	Methanol from lignocellulosic materials.	Ethanol from lignocellulosic materials
	Commercial readiness	
Commercial technology and plants in operation.	Commercial technology with one facility using wood in the planning stages; needs to be demonstrated using grasses and residues, etc.	Needs to be developed and demonstrated to be economical
	Potential production by end of 1980's	
Uncertain; could be constrained by nonenergy demand for cropland.	Greatest potential but constrained by the leadtime for constructing new facilities.	Uncertain due to R&D needs.
	Production cost par Btu	
Expected to be about the same as fuel methanol but probably greater than methanol from coal.	Expected to be about the same as fuel ethanol although probably greater than methanol from coal.	Uncertain; if produced with current technology would be more expensive than ethanol from grain or methanol; after R&D could be comparable.
	Net gasoline displacement	
If used as an octane-boosting additive and distilled without using premium fuels will have a positive net premium fuels balance; balance would be negative if used as a standalone fuel and produced from energy-intensive sources of grain.	Will have a positive net premium fuels balance. If used as an octane-boosting additive could be comparable to or perhaps slightly better than grain ethanol, but economic and most energy-efficient distribution and end-use systems need to be determined.	Expected to be comparable to methanol if premium fuels not used as distillery boiler fuel.
	Automotive performance	
New car warranties cover use of 10% blends; manageable problem in small number of cars with phase separation, fuel filter clogging; rubber and plastic could deteriorate in some cars.	New car warranties do not cover use of methanol blends. greater potential for phase separation, vapor lock, and materials damage than grain ethanol; may require other additives.	Same as grain ethanol.
	Use as standalone fuel	
Limited due to production potential; would require engine modifications; would improve auto efficiency.	Considerably greater potential; will require engine modifications; would improve auto efficiency.	Comparable to methanol,
	Use in diesel	
Can be used in diesel engines fitted for dual fuels; will displace up to 30 to 40% of diesel fuel per engine.	Comparable to grain ethanol.	Comparable to grain ethanol.
	Use in stationary applications	
Can be used in stationary applications (e.g., gas turbines); minor end-use modifications will be needed.	Comparable to grain ethanol.	Comparable to grain ethanol.
	Can be used as an octane-boosting additive	
Yes.	Yes.	Yes.
	Potential for environental damage in obtaining the feedstock	
Highest potential.	No significant potential for waste products as feedstock; some potential for crop residues but not if managed properly; high potential for wood if not managed properly.	Comparable to methanol.
	Potential for air pollution at end use	
Mixed effects in mobile sources; mainly improved emission characteristics in stationary sources, but effects of potential increase in aldehyde emissions are uncertain.	Same as grain ethanol.	Same as grain ethanol.

Box C.-What Is the Energy Balance for Ethanol Production and Use?

Roughly the same amount of energy is required to grow grains or sugar crops and convert them to ethanol as is contained in the ethanol itself. Consequently, if premium fuels (oil and natural gas) are used to supply this energy and if the ethanol is used solely for its fuel value (e. g., as in most onfarm uses), then ethanol production and use ***could actually result in an increase in*** *U.S.* ***consumption*** of ***the premium fuels.*** (Note that no such problem exists with methanol production.)

A net displacement ***of premium fuels can be achieved,*** however, by taking three steps. First, if the distillery is fueled by coal or solar energy (including biomass), then in most cases less premium fuel will have been used to produce the ethanol than it contains. For most sources of grains and sugar crops, each gallon of ethanol will contain the energy equivalent of 0.2 to 0.5 gal of gasoline more than the energy 'needed to grow and harvest the crop. (The actual value will depend on farming practices and yields.) In some extreme cases, such as grain sorghum grown in poor soil, however, the farming energy may still be greater than the energy content of the resultant ethanol.

Second, if the ethanol is used as an octane-boosting additive to gasoline, rather than for its fuel value alone, then substantially more premium fuel can be displaced. Because the oil refinery requires less energy if it produces a lower octane gasoline, the energy equivalent of up to 0.4 gal of gasoline can be saved at the refinery for each gallon of ethanol used as an octane-boosting additive (see box D for a discussion of the uncertainty associated with this estimate). An additional saving may be obtained at the point of use because automobiles appear to obtain better mileage with gasohol than would be expected from its energy content alone. Various road tests have resulted in widely varying estimates for the size of this savings, but laboratory tests and the average of all road test data are consistent with a savings of 0.15 gal of gasoline per gallon of ethanol with the existing fleet. (See vol. II "Use of Alcohol Fuels.")

Third, distilleries can take advantage of the feed value —and consequent energy credit — for their byproduct (distillers' grain or DG). With the feed rations commonly used today, DC can be a substitute for soybean meal* or other protein concentrate. The credit for displacing soybean meal is the energy equivalent of slightly less than 0.1 gal of gasoline per gallon of ethanol.

The above factors combine so that each gallon of ethanol produced from corn has the potential to displace premium fuels with the energy equivalent of up to 1 gal of gasoline. Whether this potential is actually achieved will depend primarily on the fuel used in the distillery and the end use of the ethanol.

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*M Poos **and T. Klopfenstein, "Nutritional Value of By-Products** of Alcohol Production for Livestock Feed," Animal Science Publication No. 79-4, University of Nebraska, Lincoln. Claims that DC can reduce the amount of corn needed in animal feed are based on studies using feed rations substantially different from those used commercially and therefore are not applicable (see "Fermentation" in vol. II).

Box D.-Energy Savings From Ethanol's Octane Boost

There is considerable uncertainty about the premium fuel savings obtained by using ethanol as an octane-boosting additive to gasoline. Estimates made by several groups range from near zero to more than 0.5 gal of gasoline equivalent per gallon of ethanol used. The potential energy savings will vary according to the octane boost attained (if butane must be removed from the gasoline in order to compensate for the increase in vapor pressure caused by the ethanol, the octane boost will be reduced), specific refinery characteristics (such as process design and the yield and octane level of gasoline produced), and the type of crude being processed, If the energy savings from ethanol represented the major economic incentive to the refiner, then refineries with the highest potential for energy savings would be the most likely to use it and savings would be maximized. Some refineries, however, may have additional incentives for using ethanol, including capital savings and greater gasoline yield (coupled with lower yields of process gas, butane, etc.) from reduced reforming requirements, and access to stronger markets caused by differential tax exemptions for gasohol. These incentives may not coincide with maximum energy savings.

For purposes of calculation in this report, OTA uses a value of 0.4 gal of gasoline equivalent for each gallon of ethanol used. This value corresponds to an octane boost of three (R+M)/2 octane numbers, (which OTA considers reasonable for a 10 percent ethanol blend with no adjustment for vapor pressure), and a gasoline pool octane of 91 (which should be approached as the percentage of cars using lead-free regular gasoline increases and the octane requirements for these cars increases as it has in the past). Because the value is based on a number of simplifying assumptions, it should be considered as speculative. (See "Use of Alcohol Fuels" in vol. I I for a detailed discussion of the basis for this estimate and the uncertainty associated with it.)

water heating, will account for nearly all the stationary uses of premium fuels by 2000. The principal constraint is the low-Btu content of airblown biomass gasification which will limit these uses to close-coupled gasifiers due to transportation costs. From the 10 Quads/yr increment, it may be technically possible for gasification to displace as much as 9 Quads/yr (equivalent to about 4.5 million bbl/d of oil) of oil and natural gas by **2000.**

Although biomass clearly has the potential to displace large quantities of premium fuels, one of the major effects of a large penetration of biomass probably will be less coal use than with no biomass. Coal, too, can be converted to synthetic gas and methanol as well as other synthetic liquids, and will compete for applications currently using oil and natural gas. In addition to the important economic questions of resource and conversion costs, issues such as relative environmental effects, scale of operation, and renewable versus depletable resources will play a major role in guiding policy and market choices between biomass and coal.

Does Gasohol Production Compete With Food Production?

It has been widely claimed that the byproduct of making ethanol from corn is a better feed than corn and, therefore, that gasohol will not cause food-fuel competition. OTA's analysis indicates, however, that the byproduct of making ethanol from corn is not better or worse than grains, but simply different. It is not a substitute for grain, but rather more nearly a substitute for protein concentrates, such as soybean meal, used in animal feed.[3]

Despite this substitution of distillery byproduct for soybean meal, the quantity of cropland needed to grow corn for ethanol — and thus its protein concentrate byproduct– is at least 30 to 40 percent greater than the quantity of land needed to grow soybeans for an equivalent amount of protein concentrate. *

Although additional cropland is physically available for expansion of the acreage under intensive cultivation, typical problems with this land include low productivity and periodic drought or flooding. These problems result in lower crop yields per acre and greater sensitivity to weather than average lands used for intensive crop production today, increasing the economic cost and risk of farming. Consequently, it will be necessary to raise farm commodity prices in order to make it profitable for farmers to increase the quantity of land under cultivation, although it is not known exactly what price rises will be necessary for any given level of crop land expansion.

This increase in farm commodity prices is the basic mechanism through which food and fuel compete. Consequently, although use of the distillery byproduct as feed reduces the food-fuel competition (by reducing the quantity of new cropland needed for a given level of ethanol production), it does not eliminate it.

Because of the flexibility in the agricultural system, however, the increase in average feed prices probably will not be noticeable until significantly more ethanol is being produced than at present (see box A). Moreover, there will be annual fluctuations in feed prices that are not directly related to ethanol production.

[3] M. I. Poos and T. K. Klopfenstein, "Nutritional Value of By-Products of Alcohol Production for Livestock Feeds," Animal Science Publication No. 79-4, Cooperative Extension Service, University of Nebraska, Lincoln. See also "Byproducts," under "Fermentation" in vol. II.

*See "Agriculture" in vol. II.

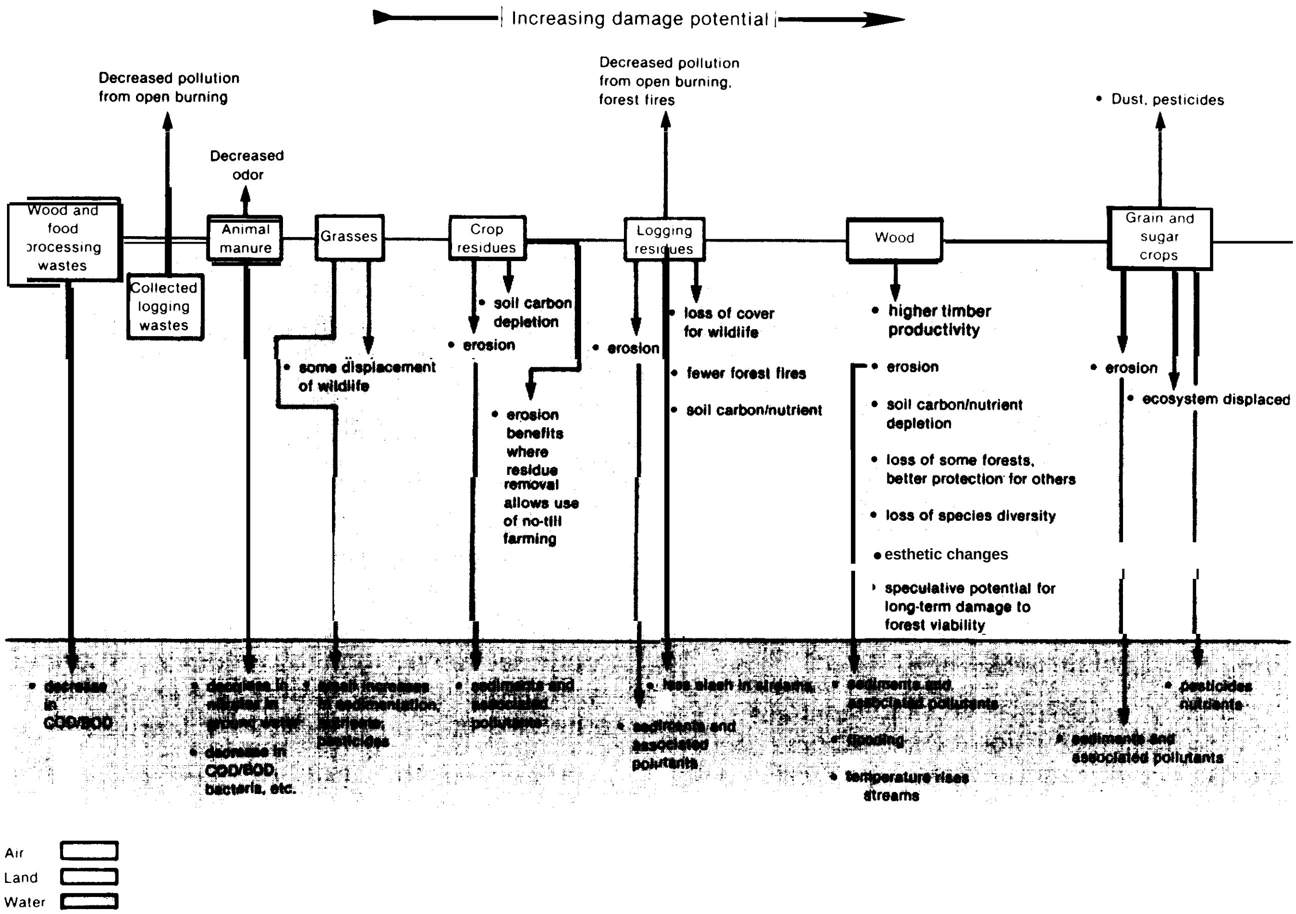
Can Biomass Feedstocks Be Obtained Without Damaging the Environment?

A portion of the potentially available biomass feedstocks may be obtained with few adverse effects on the environment. For example, perennial grasses and legumes appear to be capable of supplying as many as 4 to 5 Quads/yr without transforming other valuable ecosystems' or causing significant erosion or other damage, Similarly, obtaining supplies of manure or wood- and food-processing wastes is not likely to damage the environment and in most cases will be environmentally beneficial. For other biomass feedstocks, however, adverse environmental effects of varying significance may occur due to a number of causes (see figure 8).

Serious damage may result if the supplier does not manage the resource properly, including selecting appropriate sites and harvesting or renewing the biomass according to environmental guidelines. For example, remov-

*Assuming that large quantities of existing grasslands are not converted to row crops or other uses.

Figure 8.—Potential Environmental Damages/Benefits From Supplying Biomass Feedstocks



SOURCE Office of Technology Assessment

ing excess amounts of crop residues — or removing **any** amounts from some erosive lands — will expose soils to significantly increased erosion and subsequent damage to water quality and even to land productivity if the erosion is allowed-to continue long enough. Poor logging practices also can cause erosion, stream damage, and even increased flood danger in extreme cases of overcutting. Timber removal on some sites can lead to mass movements of soil, such as slumps or landslides, to reforestation failures, and to damage to valuable ecosystems or recreation areas. Finally, transformation of areas to single species management may cause a decline in the variety of plant and animal species supported by the forests.

Even with accepted management practices, significant environmental damage may be unavoidable if large acreages of annual crops are grown for alcohol production. Unless currently unproven strategies for crop switching and reformulating livestock feed are successful, the large-scale production of ethanol from grains and sugar crops **will** require placing millions of new acres into intensive crop production. The land available for such production generally is more erosive and may be less productive than existing farmland, leading to significant increases in already damaging levels of farmland erosion as well as in the use of agricultural chemicals.

An additional concern is the possibility of subtle, long-term declines in soil quality and forest productivity as a result of the shorter rotations and increased removal of biomass associated with intensified forest management. Similar concerns have been expressed about possible long-term soil and productivity damage associated with the collection of crop residues, even when in compliance with Soil Conservation Service erosion standards. The current state-of-knowledge does not allow definitive conclusions about either the extent of any possible damage or the potential for managing it.

Finally, although intensive timber management could increase the quantity and improve the quality of the timber available, it also will change the character of the forests. Removing logging residues and increasing stand conversions and thinning will lead to more uniform, open forests with a higher proportion of evenage, single-species stands. I n addition, populations of birds, animals, and insects that depend on dead and dying trees or large litter would decline, while other species would increase in number. Flat, easily accessible lands probably would undergo more extensive changes in forest character while steep or environmentally vulnerable lands should be less affected because harvesting often is more expensive there. These changes will be objectionable to many environmental groups, especially those concerned with preserving natural ecosystems, although other groups concerned with promoting hunting or increasing public access may welcome such changes.

Although it is difficult to predict the behavior of biomass suppliers — and, thus, the environmental impacts associated with obtaining biomass feedstocks– several factors will be important in influencing this behavior.

First, **regulatory incentives** for controlling impacts generally are not strong. The Environmental Protection Agency's (EPA) section 208 program to control nonpoint source water pollution has been slow in getting started, and its future effectiveness is unclear. Although the Forest Service appears to have good regulatory control of silvicultural practices on national forestlands, which include some of the most environmentally vulnerable wooded lands in the United States, regulation at the State level generally is hampered by insufficient agency staff or weak laws as well as by a traditional emphasis on forest fire prevention rather than silvicultural management. This is particularly true of private woodlands in the Eastern United States, where 70 to 75 percent of the potential for increased forest production exists. Most of these eastern woodlands are owned privately in small lots, making supplier behavior particularly difficult to predict.

Second, **economic incentives** for protecting the environment are mixed. Although good management may prevent some environmental damages that directly affect crop productivity and growing costs, many of the benefits of such management accrue to the public or to future generations rather than to the grower and harvester. For example, agricultural erosion is most damaging to water quality, and the major beneficiaries of erosion prevention are the downstream users of the protected stream. Any damage to productivity is in most cases a very long-term effect, while financial strains on farmers force them to value short-term gains. On the other hand, the high costs of pesticides, erosive tilling, and other mainstays of high-technology farming are leading many farmers to switch to practices that may be less damaging to the environment. In forestry, there may be pressures to harvest vulnerable sites and to "poach" wood with environmentally damaging harvesting methods. On the other hand, foresters operating on more suitable sites have a positive incentive for environmentally sound management provided by the long-term reward of good practices — a more economically valuable forest.

The strength of the incentives for and against environmental protection depends on the changing circumstances associated with the great variety of financial conditions, crop alternatives, management plans, and physical/environmental conditions applicable to biomass production. In the absence of strengthened regulations, including careful monitoring of soil and water quality, or stronger positive incentives for protection, some portion of a future biomass supply may be obtained in an environmentally costly manner.

Photo credit USDA —Soil Conservation Service

Increased incentives for environmental protection may be necessary to avoid careless logging practices on vulnerable sites

What Are the Major Social Effects of Bioenergy Production?

Bioenergy production could bring a variety of changes to society. The most important of these probably will be the effects on energy-related employment, on rural communities, and on quality of life. Some of these changes are more likely to be perceived as beneficial while others will be seen as detrimental,

I n most cases, biomass energy development will be more labor intensive than the increased use of conventional fuels, such as coal, oil, or natural gas, and therefore will result in more jobs per Quad of energy produced. These jobs are likely to occur in agriculture and forestry, in small- and medium-size businesses manufacturing conversion equipment (e. g., digesters, gasifiers, wood stoves, stills), and in the construction and operation of large-scale conversion facilities such as electric-generating stations and alcohol fuel plants.

Biomass energy resources also tend to be more highly dispersed than conventional energy sources. Feedstock transportation costs and other factors will mean that employment in harvesting, conversion, and related sectors also is likely to be dispersed. Thus, bioenergy development will avoid the public service impacts and problems of secondary development that can be associated with centralized development of fossil fuels in rural areas. Rather, in rural areas currently experiencing unemployment and underemployment, the increased resource management and capital investment associated with biomass energy are likely to be welcomed. These factors should make it easier for rural areas to plan for and achieve long-term economic growth.

In addition, biomass energy will be valued by society for its potential to reduce consumption of imported foreign oil. This displacement will be particularly valuable in agriculture, which is especially sensitive to fuel supply interruptions, but which could achieve a degree of liquid fuels or energy self-sufficiency through onfarm distillation and anaerobic digestion, as well as increase farm income through energy crop production.

Bioenergy production, however, is not without problems. First, the rates of reported occupational injuries and illnesses in agriculture, forestry, logging, and lumber and wood products are significantly higher than the national average for all private industries. The rates per worker for logging and for lumber and wood products are approximately twice those for bituminous coal mining or oil and gas extraction, while those for agriculture and forestry are comparable to coal, oil, and natural gas. Unless safer harvesting practices and equipment are developed and used, increased logging and agricultural production for energy could result in unacceptable levels of occupational injury and increased expenditures for workmen's compensation. Eventually, safety could become an issue in labor-management relations as it has in the coal mines, increasing the potential for strike-related supply interruptions in wood energy.

Second, the use of commodities for energy could lead to competition with traditional uses of these commodities. This competition could increase farmland and possibly forestland prices, and, together with the resulting land inflation, also could increase the price of food or result in changes in American dietary habits such as less consumption of meat. If the demand for food continues to rise, Americans ultimately could be forced to choose between relatively inexpensive food and relatively inexpensive fuel. Moreover, increases in U.S. food prices are likely to increase the cost of food on the international market. Some countries will not be able to afford food imports, and others will export crops now used domestically for food.

It should be emphasized that the potential for competition between bioenergy and agriculture involves only a small fraction of the total biomass resource base, but that fraction is capable of causing a major conflict. However, because of uncertainties about the timing and magnitude of investment in biomass conversion and about the future demand for food, it is not known at what level of bioenergy production prices will be substantially affected or when these price increases will become unacceptable.

What Are the Problems and Benefits of Small-Scale Bioenergy Processes?

The dispersed nature of much of the biomass resource tends to favor its use in small-scale, dispersed applications, In some cases, facilities as large as 50-MW electric-generating plants may be feasible, but the full use of resources like wood probably will require considerable participation by small-scale users. In other cases, such as grain ethanol, obtaining sufficient feedstock for large-scale conversion facilities is not a problem, but there is interest in small-scale onfarm production as a means of achieving some degree of liquid fuels self-sufficiency for farmers and as a way for them to divert some of their grain from the market when prices are low.

Some of the questions that potential small-scale users of bioenergy and biomass conversion facilities probably should ask are: 1) what fuel do they want and will it be used onsite or sold? **2)** what is the cost and reliability of their feedstock supply? **3)** what fuel will be used for the conversion facility (e. g., onfarm distilleries)? 4) how expensive, safe, reliable, and automatic is the conversion facility? and 5) what are the indirect effects of using or converting the biomass (e. g., dependence on a single buyer, potential crop rotation schemes, etc.)? The more important aspects of these technical and economic concerns about small-scale wood energy use, onfarm alcohol production, and anaerobic digestion, as well as the environmental and social effects of these systems, are considered below.

Technical and Economic Concerns of Small= Scale Wood Energy Systems

At present, small-scale wood energy systems primarily are limited to direct combustion (wood stoves) and airblown gasification (for small industrial boilers and process heat). Small methanol plants could be developed, but the costs are highly uncertain at present.

Where sufficient quantities of wood can be obtained for less than $60 to $1 00/cord (roughly $60 to $100/dry ton), burning the wood in efficient wood stoves or furnaces is competitive with home heating oil costing $0.90/gal. The actual wood cost that is competitive will depend on the relative efficiencies and costs of the conventional and wood heating systems. However, with wood-burning stoves or furnaces, it often is necessary to feed the unit manually, and frequent ash removal and cleaning are necessary for continued safe and efficient operation. It also may be necessary to prepare the wood by cutting and splitting the logs. These factors will limit the use of wood for home heating to those people who are willing to undertake these activities, who value the use of local or renewable energy supplies, or who use the wood as an insurance against shortages of their conventional home heating fuel.

With small-scale wood-fired industrial boilers, investment cost is the primary constraint. Wood-fueled boilers cost about three times as much as comparable oil-fired systems, and until lending institutions accept a wood-fueled facility as a reasonable investment because of lower fuel costs, potential users may have difficulty financing a conversion to wood energy, Also, due to uncertainties about the reliability of wood fuel supplies and conversion equipment, many potential users may wait to invest in wood boilers or gasifiers until they can obtain long-term wood supply contracts or, in the case of gasifiers, until more operating experience has been accumulated.

If reliable, easy to use gasifiers become widely available, however, the number of possible uses for biomass would increase to include process heat, and the cost of retrofitting small industrial operations for biomass could be less than for direct combustion. Moreover, users could return to oil or natural gas if temporary wood shortages developed and the other fuels were available. This could reduce or eliminate most of the potential problems with using wood energy in small industrial facilities, but could pose load management problems for gas utilities if large numbers of gasifiers were in operation.

Technical and Economic Concerns of Small-Scale Ethanol Production

Technically, it is relatively easy to produce ethanol containing 5 percent or more water in small, labor-intensive distilleries. This alcohol could be used as a supplement to diesel fuel in retrofitted diesel engines and it probably can be blended with vegetable oil (such as sunflower seed oil) and used as a replacement for diesel fuel, In either case, however, the ethanol probably would cost at least twice the late-1979 cost of the diesel fuel it would replace, In addition, if the ethanol-vegetable oil blend is used, the diesel engine probably would deliver less power than with diesel fuel unless the engine is modified to allow more fuel to enter the combustion chamber.

With slightly more sophisticated equipment and special chemicals, dry ethanol suitable for blending with gasoline could be produced onfarm, but the costs are likely to be considerably higher than for large distilleries with current technology. Process developments, particularly in the ethanol drying step and in automatic monitoring of the distillery, could make the costs competitive.

If ethanol from grains or sugar crops is used as a farm or other standalone fuel, the net displacement of premium fuel (oil and natural gas) is considerably less than if the ethanol is used as an octane-boosting additive to gasoline. For some feedstocks and regions, onfarm production and use of ethanol actually will lead to an increase in premium fuel usage. In essence, the farmer would be buying more fertilizer, pesticides, and other energy-intensive products in order to avoid buying diesel fuel; in some cases the net result would be that the costs of the farming operation would continue to be very sensitive to energy prices. For farmers who could expand their acreage under cultivation, the tradeoff between diesel fuel and other energy-intensive products would be relatively direct. For those who cannot expand their acreage, the choice is between the diesel fuel, plus other energy-intensive products that could be saved by not cultivating part of their acreage, versus the ethanol that could be produced by not selling part of their crop. Depending on the specifics of the markets and Government regulations, however, the supply of fertilizers, pesticides, and similar products may be less prone to temporary shortages than diesel fuel, and this strategy might be effective as an insurance against diesel fuel shortages.

The least expensive distillery options assume that the distillery byproduct stillage would be fed to animals in the area without being dried. This stillage, however, can spoil within 1 to 2 days and the farmer would have to change feeding practices to avoid feed contamination.[4] If there are insufficient animals in the area or feeding wet still age proves to be impractical for the farmer, then the still age would have to be dried, which would increase the cost and energy requirements of the ethanol production.

Onfarm distilleries available today require considerable monitoring and other labor for safe and reliable operation. For example, stills involve risks of fire, explosion, and exposure to moderately irritating chemicals.[5] Proper training and well-built equipment can reduce the risks, but the need for monitoring could make it impractical to operate stills during planting,

[4] t W Kienholz, D L Rossiter, et al , "Grain Alcohol Fermentation Byproducts for Feeding in Colorado, " Department of Animal Science, Colorado State University, Fort Collins

[5] N Irving Sex, "Dangerous Properties of Industrial Chemicals, " Van Nostrand Reinhold Co , New York, © 1975 by Litton Educational Publishing, Inc The hazard categories are "None, Slight causes readily reversible changes which disappear after end of exposure, Moderate may involve both Irreversible and reversible changes not severe enough to cause cleat h or permanent injury; a ncf High ma v cause death or permanent injury after very short exposure to small quantities"

harvest, and parts of the summer. However, less than full-time operation would raise the ethanol costs and make it less feasible to rely on the distillery byproduct for animal feed. This points to the need for a highly automated operation, which will increase the cost of the equipment.

Farmers producing ethanol also will have to secure a fuel for their distilleries. Crop residues or grasses may be one possibility, but technologies for conveniently burning or gasifying these fuels onfarm are not available at present and in some regions the grasses and residues also are not available. Where wood is available, this could be used. Alternatively, solar-powered equipment suitable for ethanol distillation probably can be developed, but it is not currently available and the costs are uncertain. Using biogas from manure digesters to fuel distilleries is technically possible, but the digester would add substantially to the investment costs and special financing designed to lower capital charges probably would be necessary for most small operations.

In the most favorable cases, it may be possible to produce wet ethanol onfarm in a labor-intensive operation for $1/gal plus labor. * Used in diesel tractors, this is about twice the late-1979 cost (per Btu) of the diesel fuel it could replace. There is, however, insufficient experience with onfarm production to predict costs accurately and this estimate may be low.

Nevertheless, the large subsidies currently applied to ethanol have created a market price for the ethanol that is significantly higher than the production costs. Consequently, in some cases it may be possible to produce wet ethanol onfarm and sell it profitably to large distilleries for drying. If profit margins decrease, however, onfarm ethanol production with current technology would be, at best, marginal in comparison to large distilleries.

For some farmers, however, the cost or labor required to produce dry or wet ethanol may be of secondary importance. The value of some degree of fuel self-sufficiency and the ability to divert limited quantities of crops when prices are low may outweigh the inconvenience and cost. I n other words, they may consider onfarm ethanol production to be an insurance against diesel fuel shortages and a means of raising grain prices.

Technical and Economic Concerns of Small-Scale Anaerobic Digestion

The principal concerns regarding onfarm anaerobic digestion of animal manure to produce biogas are the investment cost of the digester system and the need to use the biogas effectively. The capital charges and investment costs should decrease as digesters become commercial. But, at least in the near term, attractive financing arrangements would accelerate commercialization.

The farmer's ability to use the biogas energy effectively also will play an important role in determining the economics. Many digesters will produce more energy than can be used on the farm but in a form that cannot be sold easily (the biogas or waste heat). Furthermore, the farm's energy use may have to be managed in order to reduce daily peaks that would make the economics of using biogas less attractive. Also, the operation may have to be expanded to include such things as greenhouses so that all of the energy produced can be used. To the extent that the biogas is used to generate electricity onfarm, the economics also will depend heavily on the prices that the electric utility is willing to pay for wholesale electricity and the charges for backup power.

Environmental Effects of Small- Scale Biomass Energy Systems

The small-scale biomass systems, especially energy conversion systems such as wood stoves, onfarm stills, and anaerobic digesters, create both opportunities and problems for environmental control.

Smaller systems afford some opportunities for using the assimilative capacity of the environment for waste disposal that are impractical for large centralized systems. For example, liquid wastes from small ethanol and biogas plants often can be safely disposed of by land application. Large plants may find this option closed to them because of difficulties in finding sufficient land.

'See "Fermentation" in Vol II

This advantage may be overbalanced by several problems associated with small-scale operations. Effective "high technology" controls, such as water recycling, often are unavailable to smaller plants. Monitoring and enforcing environmental standards are complicated by the larger number of sites. Poor maintenance of equipment and training of operators as well as ad hoc design may present potentially significant safety as well as environmental problems.

Aside from different control options and regulatory problems, the size of biomass facilities affects the nature of their impacts, Effects that are primarily local in nature, such as damage from fugitive dust, toxic waste disposal, and the effects of secondary development, are less severe at any site but occur with greater frequency. Emissions of polycyclic organic matter, generally not a problem with large combustion sources, may be a significant problem with smaller less efficient sources such as wood stoves. Finally, regional air pollution problems caused by the long-range transport of pollutants associated with the tall stacks of larger plants are traded for increased local problems caused by emissions from low stacks. This latter effect might increase State and local governments' incentive to require adequate controls, because the major air pollution damages from energy conversion facilities will no longer occur hundreds or thousands of miles away.

Social Considerations of Small-Scale Bioenergy Production

The social impacts of commercial-scale bioenergy production discussed above are not necessarily applicable to small-scale systems. For example, although new jobs will be associated with the manufacture, distribution, and servicing of small-scale conversion equipment, obtaining the fuel for and operating the equipment are more likely to be associated with additional personal labor or a second family income. Similarly, if bioenergy development focuses on small-scale systems it is less likely that competition with nonenergy users for resources would occur, because in the sectors where competition could be harmful, smaller systems will allow greater control over the amount of the resource base that is devoted to energy.

On the other hand, some social considerations are more likely to arise with, or would be exacerbated by, an emphasis on small-scale systems. For example, smaller systems pose additional health and safety problems, including the hazards to amateur woodcutters, the risk of house fires from improperly installed or maintained wood stoves, and fires or explosions from leaks in small stills. In addition, small stills may represent a source of alcohol that is attractive to minors but can contain poisonous impurities such as fusel oil, acetaldehyde, and methanol.

Small-scale systems also will be more difficult to regulate than commercial-scale technologies. The primary concerns here are the Bureau of Alcohol, Tobacco, and Firearms permitting and other requirements designed to prevent unauthorized production or distribution of beverage alcohol, and environmental regulations intended to protect public health from the process chemicals in distillery effluents and from the uncontrolled combustion of solid, liquid, and gaseous fuels.

Lastly, smaller systems probably will have a greater impact on lifestyles. Even with the development of relatively automatic equipment, small-scale bioenergy conversion will require individual labor — personal or hired — in order to ensure a reliable supply of energy. For some people, the increased price of traditional energy sources may not be a sufficient incentive to outweigh the convenience of delivered energy. This convenience factor may be the primary constraint on the widespread adoption of small-scale systems.

What Are the Key RD&D Needs for Bioenergy Development?

A relatively complete list of the important RD&D needs for bioenergy development is given in appendix A. Certain of these, however, appear to be particularly important to the smooth and effective development of bioenergy as a replacement for premium fuels or as a liquid fuel that can be produced onfarm. It should be remembered that important developments can occur in other areas, but success in those listed below are especially important or would be particularly effective in the near to mid-term:

- **Crop development.–-A** variety of energy crops, especially high-yield grasses, should be developed. The emphasis should be on crops that do well on land poorly suited to food production and that require a minimum of energy inputs relative to the output. Various crop-switching possibilities that enable fuel production with a minimum expansion of cropland in production also should be investigated. (The Federal Government supports a limited amount of research in this area, but it does not include systematic comparative crop evaluations that focus on energy product ion.)
- **Forest management.—** Forest management practices and the related equipment should be improved and forest landowners encouraged to manage their resource in a way that is environmentally sound and that increases forest productivity. This will necessarily involve basic and applied research to improve knowledge of what these practices should be, and to determine the effects of intensive silviculture on long-term forest productivity. (The U.S. Forest Service supports research in this area, but it generally has not integrated fuel production with conventional forest products production and forest management.)
- **Gasifiers. –A** variety of inexpensive, efficient, and reliable gasifiers capable of using wood and plant herbage should be developed. These would include small, airblown gasifiers for process heat and boiler retrofits, oxygen-blown and pyrolytic gasifiers for improved methanol synthesis, and pretreatments such as densification of plant herbage that may be useful for improving the feedstock's handling characteristics. Basic and applied research into biomass thermochemistry and secondary gas phase reactions would provide engineers with information for improved gasifier design and would create new opportunities to produce fuels and chemicals from biomass. (The Department of Energy (DOE) supports very little research in this area.)
- **Ethanol synthesis.–** In order to provide economic alternatives to using grain and sugar crops for ethanol synthesis, processes using wood and plant herbage to make ethanol should be researched, developed, and demonstrated. (DOE supports some research in this area.)
- **Use of methanol.–** Various strategies for using methanol in gasoline blends should be developed and compared. Inexpensive technology that will enable engines fueled with pure methanol to start in cold weather also should be developed. (DOE is supporting some research in the area.)
- **Onfarm liquid fuels production.–** If onfarm liquid fuel production is to be promoted, inexpensive, highly automatic, small-scale ethanol stills should be developed, including options for producing dry ethanol and dry distillers' grain, and for using a variety of solid fuels commonly found onfarm. Other onfarm liquid fuels options such as small sunflower seed presses also should be investigated and, where appropriate, developed. (DOE and USDA are supporting some research in this area.)

What Are the Principal Policy Considerations for Bioenergy Development?

The issues discussed above point out the potential benefits and problems of increased reliance on biomass energy sources in the United States. Bioenergy is both renewable and domestic and would therefore help reduce U.S. dependence on costly and insecure imported oil and on depleting fossil fuels. However, bioenergy also may have important, but difficult to predict, effects on the environment and on prices for food, feed, fiber, and land. The primary policy considerations that are raised by the potential problems and benefits of bioenergy development are reviewed below.

First, a number of measures have been proposed or passed by Congress to promote new energy sources of all kinds, and many of these will improve the prospects for investment in bioenergy. However, because of the wide range of biomass feedstocks and conversion technologies, many bioenergy systems would benefit more from policies carefully tailored to these feedstocks and technologies. These could include programs to provide information and technical assistance to bioenergy users and to develop reliable supply infrastructures for energy uses of biomass resources.

Second, because of uncertainties about the sources of bioenergy feedstock supplies, the introduction of biomass energy should be monitored carefully. For example, if commodity prices rise i n response to bioenergy development, Congress might choose to reevaluate promotional policies and adjust them if necessary, For this reevaluation, legislators could use measures such as "sunset" provisions and price and quantity thresholds for subsidies, as well as statutory requirements for the review of existing policies. In addition, rapid development, demonstration, and commercialization of economic processes for producing ethanol and methanol from lignocellulosic materials would reduce the energy demand for grains and sugar crops.

Uncertainties about future biomass resource harvesting and management practices make it important to monitor the environmental impacts of bioenergy development as well. For example, with proper management the quantity and quality of timber available for wood energy and for traditional wood products could increase, Without such management, however, harvesting fuelwood could cause severe water pollution as well as declining land productivity. Other bioenergy sources threaten environmental problems of similar importance. Consequently, the environmental effects of obtaining all major biomass resources should be monitored, and new and expanded programs and incentives should be used to encourage sound resource management practices.

I n addition, using biomass for energy and for chemical feedstocks will link economic sectors that previously were independent of each other. These links could have significant institutional implications for regulation, such as that related to antitrust.

Finally, concerns have been raised about the magnitude and duration of bioenergy subsidies. Gasohol, for example, already receives Federal and State subsidies in the form of tax exemptions that can total as much as $56/bbl of ethanol. * Such subsidies, especially if they are continued for long periods of time, distort consumer perceptions of the true cost of bioenergy.

'See "Alcohol Fuels" in ch 5

Chapter 4

FUEL CYCLES AND THEIR IMPACTS

Chapter 4.–FUEL CYCLES AND THEIR IMPACTS

TABLES

FIGURES

BOX

Chapter 4
FUEL CYCLES AND THEIR IMPACTS

Introduction

All the combinations of different kinds of bioenergy resources, conversion technologies, and end uses would lead to numerous fuel cycles—far too many to analyze in-depth in this report. Consequently, four biomass fuels were chosen — wood, alcohol, herbage, and animal manure—that could play a major role in bioenergy development between 1980 and 2000.

This chapter presents an overview of some environmental and social implications of bioenergy in general, and then reviews the technical, economic, environmental, and social considerations specific to each of the four fuel cycles. The chapter ends with a consideration of two possible energy futures and the role bioenergy could play within each in displacing conventional fuels.

Environmental Impacts—Generic Concerns

A major conclusion that can be drawn from OTA's analysis of the environmental effects of biomass energy (see vol. II) is that while biomass fuels may be potentially less harmful than the most damaging fossil alternative—coal — severe environmental degradation may still accompany their use. The Federal Government will have to exercise great care in providing incentives for biomass energy to avoid promoting environmentally harmful practices or expansion into vulnerable land areas.

Decentralized Conversion Facilities

The technologies that transform raw biomass resources into usable fuels or electricity are often somewhat similar to technologies for burning coal or transforming it into synthetic fuels, However, the low quantities of toxic materials in the biomass raw materials and the availability of biological as well as thermochemical means of producing gaseous and liquid fuels generally yield a lower *potential* for environmental degradation than experienced with coal conversion technologies. On the other hand, the greater simplicity of the biomass technologies and their lack of demanding physical operating conditions allow some types of biomass facilities to operate at a scale that is much smaller than would be practical with coal conversion technologies. This potential for decentralization is often praised by consumer and environmental interests, but it makes the careful monitoring of environmental conditions and the enforcement of control requirements more difficult. Environmental protection authorities can expect to have problems with these facilities similar to those they encounter with existing small pollution sources, For example, automobile owners often try to circumvent pollution control systems they perceive to be inconvenient. In dealing with autos, State agencies can require automobiles to be driven to a central facility for inspection–an option not available for monitoring emissions from anaerobic digesters, for example. The small size of many biomass conversion facilities also tends to eliminate capital-intensive, technologically sophisticated options for pollution control However, the smaller size may open up greater potential for using the assimilative capacity of land and water to dispose of biodegradable wastes. In many areas of the country, the extensive contiguous land areas or high-volume streams needed for waste disposal from large facilities are not available, while more modest land areas or streams are.

Aside from influencing the pollution control options available and the regulatory difficulties encountered, the small size of biomass conversion facilities will affect the nature of the environmental impacts that may occur. Some effects that are primarily local in nature — toxic waste disposal problems, increased air pollution and other damages from secondary development, depletion of local water supplies — will be less severe at any site but will occur at more sites, Regional water supply problems could be eased because the multiple plants may have greater flexibility in locating otherwise-unused water supplies, The generally smaller size of the plant stacks could allow more of the plant emissions to fall out close to the plant, in contrast to the 500 ft and higher stacks of large powerplants which make their emissions more of a regional than a local problem. Thus, regional problems caused by the products of long-range transport and transformation — such as acid rain — might be eased at the expense of increased local problems with directly emitted gases and particles. This might have a salutary effect on local and State governments' willingness to require and enforce adequate controls, because the air pollution damages from uncontrolled facilities will tend to occur within the governments' jurisdictional boundaries rather than hundreds of miles away,

Feedstock Production

The growing and harvesting of the more conventional biomass resources — wood and agricultural products and residues — involve primarily extensions or more intensive applications of present forestry and agricultural practices, Thus, many of their environmental implications are generally familiar to the regulatory agencies, but they are by no means environmentally benign, Although forestry and agriculture are not usually associated with the severe environmental damage caused by mineral and fossil fuel extraction technologies such as coal mining, they can cause severe land degradation and water pollution if they are mismanaged. The extent of any damage will depend more on the behavior of the exploiting industries than on any inherent problems in the growing and harvesting systems themselves. Thus, the major question to be asked in an analysis of biomass energy's environmental effects is, "How will the farmer/landowner/forester behave?" The answer will depend on **economics** (Does erosion control pay, given the present price of corn?), on the **swiftness of development** (Will there be enough time for planning, for selecting the right lands?), and on the **scale of development** (How much pressure will be placed on undeveloped, unmanaged lands?).

The growing and harvesting of biomass feedstocks also present a special enforcement problem to environmental protection authorities. These activities are important "nonpoint" sources of such water pollutants as sediments, nutrients, salts, and pesticides. Although section 208 of the Clean Water Act established a comprehensive areawide planning and management mechanism to control nonpoint source pollution, a recent General Accounting Office report acknowledges that progress in controlling this pollution has been minimal.[1] The ninth annual report of the Council on Environmental Quality says that:

> The slow progress of the Section 208 program continues to frustrate water quality managers and many citizens. The program has been difficult to implement because of funding impoundments, lack of data on nonpoint source pollution, and the slow development of economical control techniques. The dominant problem appears to be an institutional one . . . The incentives for local governments to develop and implement effective water quality management programs are limited and often overshadowed by . . . statutory compliance dates for point sources.[2]

A number of factors impede effective nonpoint source control:

- **multiplicity of sources** — the number of sources that require monitoring and their geographic separation represent a difficult logistical problem for State and local agencies with limited resources;

[1] *National Water Quality Goals Cannot Be Attained Without More Attention to Pollution From Diffused or Nonpoint Sources* (Washington, D.C.: General Accounting Office), CED-78-6.

[2] *Environmental Quality: Ninth Annual Report* (Washington, D.C.: Council on Environmental Quality, December 1978).

- **control techniques—** compounding this logistical problem is the important role that day-to-day management, rather than the installation of easily inspected control equipment, plays in controlling nonpoint source pollution;
- **source identification—** the lack of an effluent stream leads to difficulties in identifying pollution sources; and
- **visibility—** the diffused nature of the nonpoint 'source pollution in **some cases** makes the large point source a more visible and politically acceptable target than farms and other seemingly benign nonpoint sources.

The pollution problems caused by a large-scale biomass program may be difficult to control because of these enforcement problems. Policy measures that place upward pressure on demand for biomass resources **without simultaneously providing economic incentives for better land management** may result in significant degradation in land resources.

Reduction in Use of Alternative Energy Sources

A careful evaluation of alternative biomass sources should include analyses of the environmental damage forgone by biomass substitution for coal, imported oil, and other sources as well as the impacts of growing, harvesting, and using the biomass resource (figure 9).

Figure 9.—Major Environmental Risks—Comparison of Biomass and Coal Fuel Cycles

	Biomass	Coal
Land	Large land areas permanently affected: • ecosystem displacement and loss of diversity, • erosion, • esthetic changes, and • possible soil depletion over the long term.	Smaller land areas affected at any one time: • reclamation failure and subsidence, and • erosion.
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. • Acid mine drainage (but generally well controlled now). • Sediments-more localized, effect of new surface mine law not yet determined.
Air	• Local problems with unburned hydrocarbons, particulate, CO, H_2S, odors.	• Local dust problems (mines). • Problems associated with long-distance transport of sulfur and nitrogen compounds, fine particulates, and possibly oxidants (acid rain; health effects-possibly including excess deaths; crop damage; visibility degradation). • Possibility of climate changes from CO_2 emissions.
institutional	Regulatory difficulties with: • multiple small sources and • nonpoint sources.	• Very expensive controls, especially for air pollution. • More centralized systems, maybe more amenable to regulation under current programs.
Safety	• Significant problems with obtaining feedstocks and with small-scale conversion, especially wood stoves.	• Significant problems with mining, especially underground.

SOURCE Office of Technology Assessment

Some biomass fuel cycles are direct substitutes for nuclear or fossil-fueled electric power generation; these cycles include electric generation from wood and wood wastes and residues, agricultural residues, and lignocellulose crops. When biomass substitutes for new conventional generation capacity, in most instances this capacity will be nuclear- or coal-based because of Federal restrictions on the use of oil and natural gas by utilities. Current difficulties with nuclear power imply that coal will become the major fuel for new generation capacity. **In most instances, biomass-generated electricity will reduce the need for coal-fired electrical generation.**

Where biomass is used to produce a premium fuel (e. g., alcohol) or is used in a way that allows the displacement of oil (e. g., close-coupled gasifiers and wood stoves), the fuel cycle may be said to reduce the need for imported oil or synthetic oil from coal or oil shale.

Carbon Dioxide Balance

One possible benefit of this substitution of biomass fuels for fossil fuels is said to be a net reduction in the emissions of carbon dioxide (CO_2) from energy use. The continuing buildup in atmospheric CO_2 concentrations associated with increasing fossil fuel use eventually may cause significant changes in the Earth's climate. (This issue has been dealt with at some length in a recent OTA report.[1])

The extent to which a substitution of biomass fuels for coal and other fossil fuels would moderate the CO_2 buildup depends on the degree of substitution and the net carbon balance of the biomass fuel cycle.

The U.S. share of global energy use is about one-third of the total and is likely to drop in the future as the developing nations strive for industrialization and enter a period of rapid energy growth while the United States restricts its growth. Also, biomass energy could yield at most 20 percent of U.S. energy supply by 2000 (assuming maximum biomass growth coupled with strong conservation measures). Thus, the effect of biomass energy on CO_2 levels can be significant only with very high worldwide usage and only in conjunction with other measures — promotion of conservation, nuclear power, and solar energy—that would yield the same type of reduction.

In addition, most of the proposed biomass fuel cycles use fossil fuels and reduce the mass of carbon stored in the standing biomass or soil— and therefore are net producers of CO_2. For example, the agricultural component of a corn-based gasohol fuel cycle consumes large quantities of fertilizers derived from natural gas as well as diesel fuel, petroleum-based pesticides, and other fossil fuel products. The ethanol distilleries may use coal as a boiler fuel, although they could be powered with wood or crop residues. Agricultural systems that involve forest clearing or wood systems that maintain a younger forest reduce the standing biomass, while systems that prevent the replenishment of soil organic matter (by removing residues) or hasten organic matter decomposition (by cultivating or merely exposing the soil to greater sunlight) cause a decrease in the soil carbon level.

OTA's conclusion is that biomass energy use does offer some potential for moderating the expected increases in atmospheric CO_2 levels, but any actual effects would be significant only if biomass substitution for fossil fuels was very large and if the systems were chosen with carbon retention in mind. Research on the effects of various agricultural and silvicultural practices on soil carbon levels would increase the potential for designing biomass systems that have favorable carbon balances.

[1] *The Direct Use of Coal Prospects and Problems of Production and Combustion* (Washington, D C Office of Technology Assessment, April 1979), OTA-E-86, GPO stock No 052-003-00664-2

Social Implications—Generic Concerns

Biomass energy development could bring a variety of changes to society, and its basic institutions, such as family, community, government, and the interrelationships among them. These include changes that are more likely to be perceived as important at the local level (such as effects on employment, demography, public services, and quality of life) as well as those that can be national or international in scope (e. g., changes in land and food prices, landownership, and ethical considerations). Some of these social changes could be seen as beneficial by those affected while others may be viewed as drawbacks. This section discusses the implications of social impacts that are common to all four biomass fuel cycles. Those that are specific to a particular fuel cycle are analyzed in subsequent sections.

It should be noted that any discussion of the social impacts of biomass energy is subject to a number of uncertainties that stem from the inappropriateness of impact assessment methodologies that were designed for large-scale conventional energy projects and from the lack of knowledge about the magnitude and location of future biomass development. Consequent y, this report can only identify some of the potential social changes that could occur if biomass energy technologies were adopted widely

Quantitative estimates of the employment increases associated with various levels of biomass development are given in the individual fuel cycle sections These increases are significant because of their impact on energy-related employment, their differences from conventional energy development, and their implications for the rural economy and the quality of life associated with it.

In general, biomass energy development is likely to be more labor intensive than the increased use of coal, oil, or natural gas. Thus, bioenergy should result in more energy-related employment per Quad than these other energy sources, The increased employment associated with biomass would occur in forestry and agriculture, in the manufacture, distribution, and servicing of conversion equipment, and in the construction and operation of large-scale conversion facilities.

In addition to being more labor intensive, bioenergy resources also tend to be more highly dispersed than conventional energy sources. Due to the resulting transportation costs, the jobs created in harvesting and in conversion facilities and related industries also are likely to be dispersed and are more likely to alleviate unemployment and underemployment among rural residents than to attract immigrants. Therefore, bioenergy use may help to revitalize rural economies while avoiding the rapid development and the related "boomtown" syndrome of social disruption that can be associated with large-scale centralized development of conventional energy sources in rural areas. On the other hand, large biomass facilities, such as some conversion plants, could be comparable in scale to some coal-fired facilities. If these are located in rural areas with inadequate infrastructures, temporary shortages of housing, education, and medical facilities, and other public and private sector goods and services could occur during construction. These impacts will be m i nor, however, compared to those associated with coal and oil shale development in the West.

Where large-scale centralized biomass conversion facilities are appropriate, they probably would be owned by utilities or corporations that would favor long-term "captive" sources of feedstock supply. Such sources of supply could take the form of vertical integration, in which the facility operator would purchase timberland or farmland, or they could be obtained through contractual integration — the use of long-term exclusive contracts with suppliers. In other words, vertical integration would lead directly to increased corporate ownership or control of large tracts of biomass resources. Contractual integration could have a similar but indirect result because facility operators would prefer to deal with a small number of large suppliers.[4] Therefore, large-

[4] Harold F. Breimyer, *Individual Freedom and the Economic Organization of Agriculture* (Urbana, Ill.: University of Illinois Press, 1965)

scale centralized biomass energy use could result in the local benefits being captured by utility or corporate investors and large landowners, and owners of small tracts of biomass would have difficulty competing in the same market.

On the other hand, an emphasis on small-scale bioenergy conversion systems — particularly ethanol stills and anaerobic digesters–- could contribute to energy self-sufficiency in agriculture. In addition, development of a wide range of small-scale technologies could have important values for the United States' competitive position in international markets through an expansion of our export trade in these technologies.

Increased production and use of bioenergy also can have significant effects on lifestyles and quality of life. These might include changes in the level of personal involvement in obtaining energy, in attitudes toward resources, and in the potential for persona l and occupational safety hazards.

Many of the conversion technologies are appropriate for use by individuals (e.g., wood stoves, onfarm stills, anaerobic digesters). Even with the development of relatively automatic equipment, ensuring a safe and reliable supply of energy from these technologies will, in many cases, be labor intensive in comparison with conventional fuels. For some people, the price of traditional fuels may not be a sufficient incentive to outweigh the convenience of delivered, relatively trouble-free energy.

However, this level of personal involvement in obtaining energy might foster a better understanding of the carrying capacity of the Earth's resources. For example, farmers will associate more readily with the number of acres of corn it takes to fuel their machinery for a year than they would with the fuel equivalent in barrels of oil and what that means to the world's oil resources. Similarly, improper management of renewable agricultural and forestry resources would have a greater visibility to more people than do empty oil and gas wells or even coal mining except in coal-producing areas.

Finally, both small- and commercial-scale biomass production poses significant safety hazards. These range from exploding stills and fires caused by wood stoves to the high rate of occupational injury in timber harvesting. Aside from the personal costs of these hazards, they increase the indirect costs of bioenergy production due to higher insurance and workmen's compensation rates, decreased labor productivity, and heightened labor-management conflicts.

Wood

Introduction

Wood, the Nation's leading fuel until the second half of the last century, currently supplies about 2 percent of U.S. energy. As a future source of energy, it has distinct advantages. Wood is a domestic energy source, it is renewable, it is widely available, and it is relatively abundant. Wood's major drawbacks are its solid term and its low energy content per pound compared with other fuels such as oil or gas.

OTA's analysis indicates that wood will continue to be the most important energy source from among the Nation's biomass energy resources at least to the year 2000. The energy supplied by wood in the United States, currently about 1.4 to 1.7 Quads/yr, could increase to 5 to 1() Quads/yr in the next *20* years without serious environ mental or economic repercussions. However, if attention is not given to careful forest management the potential for wood energy might be considerably less and the environmental damage significant.

An examination of the data on current management practices, the variety of positive and negative incentives for pursuing various wood supply strategies and management practices, the complexity of landownership patterns, the wide variation in forest conditions, and the variety of competing markets for wood products, leads to the conclusion that at this time **it is impossible to predict in detail what the supply response to a strong demand for wood fuels will be.** This, in turn, makes it difficult to predict accurately what the environmental and social effects of such a demand will be. Nevertheless, reasonable guesses can be made about how a strong wood demand might change the way wood is harvested in the United States and how this could affect society and the environment. In view of the high level of uncertainty, however, it is important that any program to increase the use of wood for fuel proceed slowly enough to allow "midcourse corrections."

How will a strong demand for wood-for-energy change U.S. forest management? In the absence of large increases in fuelwood demand, increasing demand for other wood products is likely to lead to:

- some increases in intensive management on the best lands;
- increased harvesting of mature stands in the West;
- access of logging to an ever-increasing proportion of commercial forest land; much of the logging may be high-grading (i. e., removal of only the most commercially valuable trees) with relatively long rotations; and
- continued increase in the use of low-quality wood for manufactured wood products.

A strong fuelwood demand may lead to:

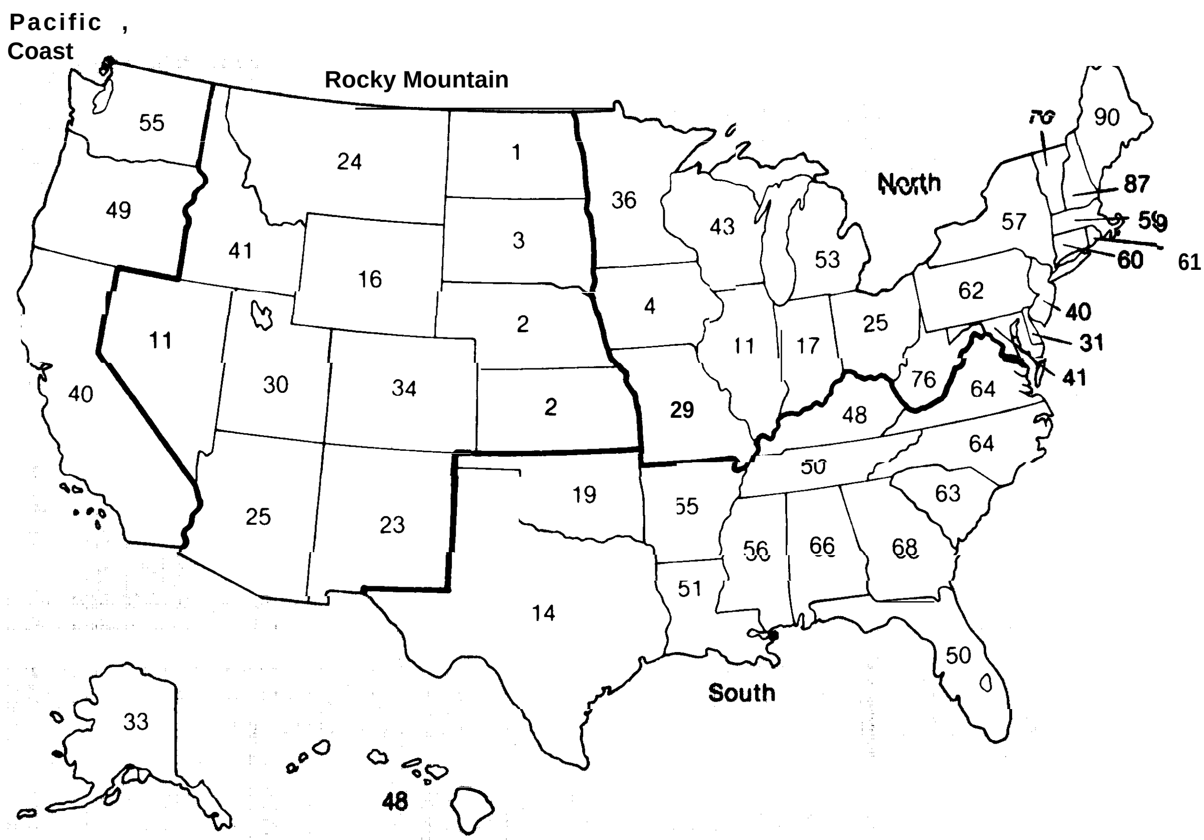
- large increases in intensive management, with shorter times between thinnings, more complete removal of biomass, increased use of improvement cuts, more conversion of low-quality stands;
- not necessarily much change in the total land area subject to logging, but much greater acreage treated *yearly;*
- eventually, increases in the availability of high-quality wood, with a decrease in logging pressure on lands of high recreational, esthetic, or ecological value; and
- increased harvest of forest land with lower productive potential.

Technical Aspects

Today about one-third of the United States — approximately 740 million acres — is forested. Of this area, 488 million acres are "commercial" forest land, that is, land capable of producing at least 20 ft^3 of wood annually but which has not been set aside as parkland or wilderness area. * For illustrative purposes, U.S. forestland may be divided into two regions, the East and the West. The East includes the North and South regions (figure 10). This area contains about 74 percent of the total commercial forest acreage in the country (figure 11). Most of the forestland in the East is privately owned, and many of the owners are farmers and others who are not primarily concerned with the commercial value of the wood on their property. The West, which contains 26 percent of the commercial forest, is made up of the Rocky Mountain and Pacific coast regions, plus Alaska and Hawaii. Seventy percent of the Western forests are federally administered (by the Forest Service and, to a lesser extent, the Bureau of Land Management). About three-quarters of the U.S. timber demand is for softwood, which is used in construction and paper production, while the remainder is for hardwood.

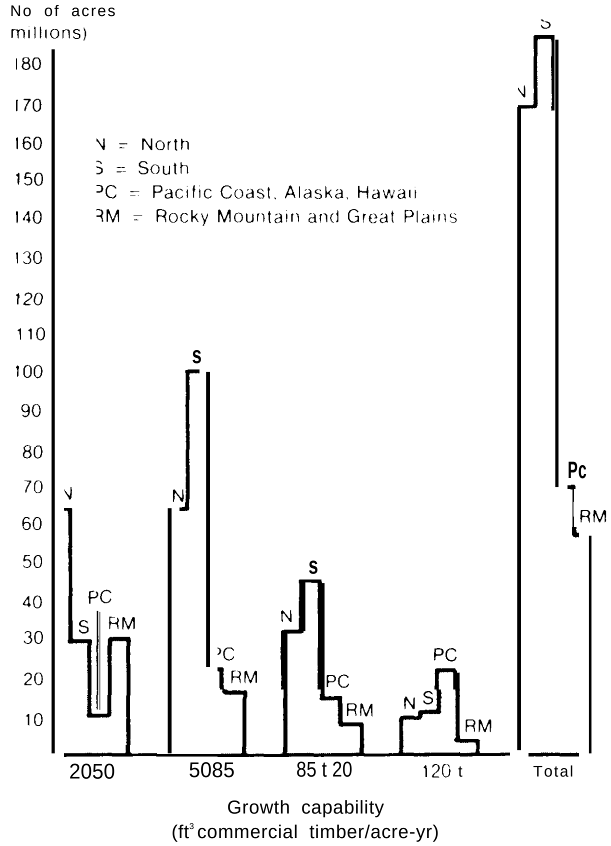
*Commercial forestland occupies 22 percent of the surface area of the 50 States and 66 percent of total forestland.

Figure 10.—Forestland as a Percentage of Total Land Area



SOURCE Forest Service U S Department of Agriculture

Figure 11.—Area of Commercial Timberland by Region and Commercial Growth Capability as of January 1, 1977



SOURCE: Data from *Forest Statistics, 1977*, Forest Service, U.S. Department of Agriculture, 1978

The West produces mainly softwood used in the production of lumber, while the East produces both softwood and most of the country's hardwood.

At present, wood with an energy equivalent of about 5 Quads is being cut from U.S. forests annually (figures 12 and 13). Of this, 1.7 Quads/yr end up as finished forest products—lumber, furniture, paper, etc. About 1.2 to 1.3 Quads/yr are burned by the forest products industry for energy. Another 0.2 to 0.4 Quad/yr is burned in home stoves and fireplaces. About 2 Quads/yr are either returned to the forest soil by means of biological decomposition or are burned at the logging site.

As table 3 shows, the potential of U.S. commercial forests is substantially higher than current output. Achieving this potential, however, will require more intensive forest management. Note particularly that 70 to 75 percent of the potential wood growth comes from the Eastern United States. Furthermore, a lot of forestland in the East has been partially harvested several times with the highest value trees being removed, leaving the poorer quality timber for further growth. It is on these lands especially that more intensive forest management will include clear cutting and replanting with trees of higher commercial value. In addition, stands of trees will have to be thinned, removing brush and poorer quality timber as well as dead or diseased trees, in order to enhance the growth of the preferred trees. In time, however, the fuelwood harvests would come mostly from the removal of logging residues, various types of thinnings, and the removal of dead, dying, and diseased trees

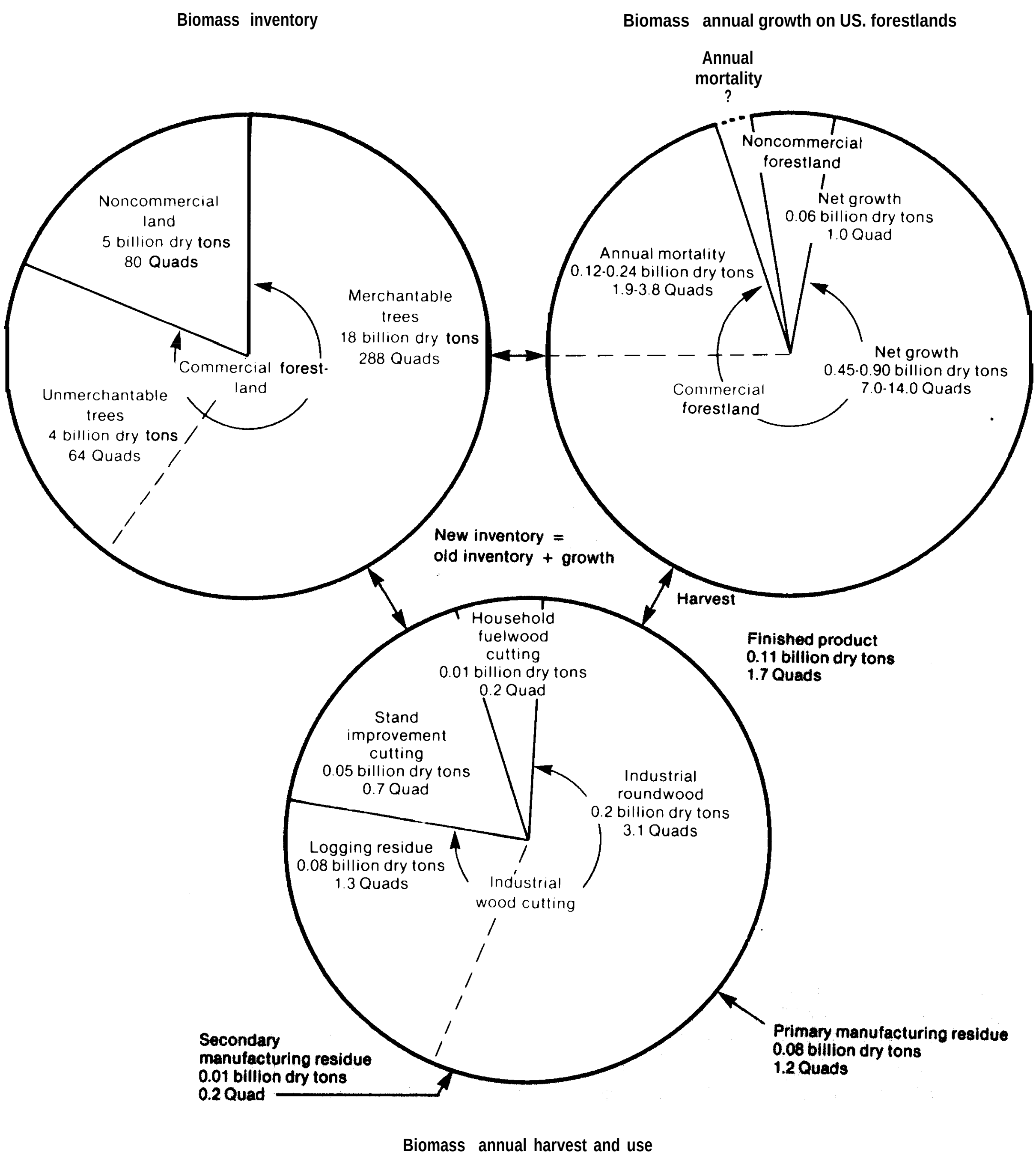
Intensive management schemes produce substantial quantities of residues suitable for energy while increasing the growth of high-quality timber. In other words, increasing the supply of high-quality timber to meet the increased demand for forest products and increasing the supply of fuelwood to meet increased energy demand are at least partially compatible goals.

Assuming that the output of the forest products industry doubles by 2000—a common industry estimate[5]—wood with an energy equivalent of 3.4 Quads/yr would end up as finished forest products. The remainder of the practical harvest potential—or about 5 to 10 Quads/yr—could be used for energy. This estimate is based on a number of assumptions, and the actual amount that eventually is used for energy will depend on complex economic factors that are discussed in the next section.

Currently the forest products industry consumes 2.7 Quads/yr of energy, including wood, oil, natural gas, and some coal. If the industry output in fact doubles by 2000 and if there is a modest improvement in its efficiency of energy use, then the forest products industry could be consuming 4 to 5 Quads/yr. Wood could supply much of this energy.

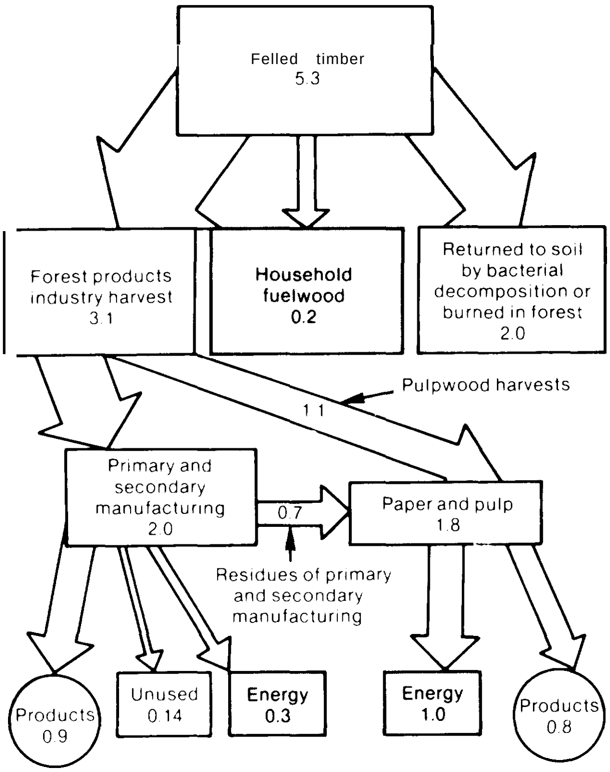
[5]Private communication with Kip Howlett, Georgia Pacific Corp., Atlanta, Ga., 1979

Figure 12.—Forest Biomass Inventory, Growth, and Use (billion dry tonnes with equivalent values in Quads)



SOURCE Ott Ice of Technology Assessment

Figure 13.— Material Flow Diagram for Felled Timber During Late 1970's (Quads/yr)



Total left in forest	2.0 Quads/yr
Total used as energy	1.5 Quads/yr
Unused residues	0.14 Quad/yr
Total products	1.7 Quads/yr

SOURCE Office of Technology Assessment

Table 3.— Potential Wood Availability by Forest Region

Forest region	Area of commercial forestland[a] (million acres)	Percent federally owned	Potential wood for energy and nonenergy uses[b] (Quads/yr)
South	1884	7.6	3.0-60
North	170.8	6.6	2.3-4.6
Pacific Coast	708	50.8	14-2.8
Rocky Mountains	578	66.1	0.6-1.3
Total	487.7[c]	20.4	7.3-14.6[c]

[a]Commercial forests are those that have good productive potential and have not been set aside as wilderness areas parks or land reserves About two-thirds of the forest land in the United States is classified as commercial
[b]Assuming 40 percent of the total growth potential (18 to 36 Quads/yr) is accessible (See Forestry Under Biomass Resource Base in vol II) Note that relative productivity factors as follows are assumed Pacific coast = 1 South = 078 North = O 66 Rocky Mountains = O 58 These are calculated from the weighted average productivity potentials for the various Commercial forest lands using data from USDA *Forest Statistics* 1977
[c]Sums may not agree due to round off error

SOURCES Office of Technology Assessment and U S Department of Agriculture *Forest Statistics of the* U S 1977

Photo credit USDA Bill Marr

Intensive timber management

The demand for wood energy by other industries as well as other sectors of the economy — residential, commercial, and transportation — will probably increase too in the coming years. How much it increases will depend on the availability and price of the competing fuels — oil, natural gas, and coal — as well as incentives to encourage its use and the availability and price of wood for energy

Wood can be burned directly to produce home heat and hot water, industrial process steam, and electricity. It can be gasified in air-blown gasifiers to produce a fuel gas that can be burned in industrial boilers or for process heat, where oil or natural gas is currently used. Wood can also be converted to liquid fuels — including methanol through gasification and synthesis from the gas, ethanol through fermentation, and pyrolytic oil through slow heating under pressure (figure 14)

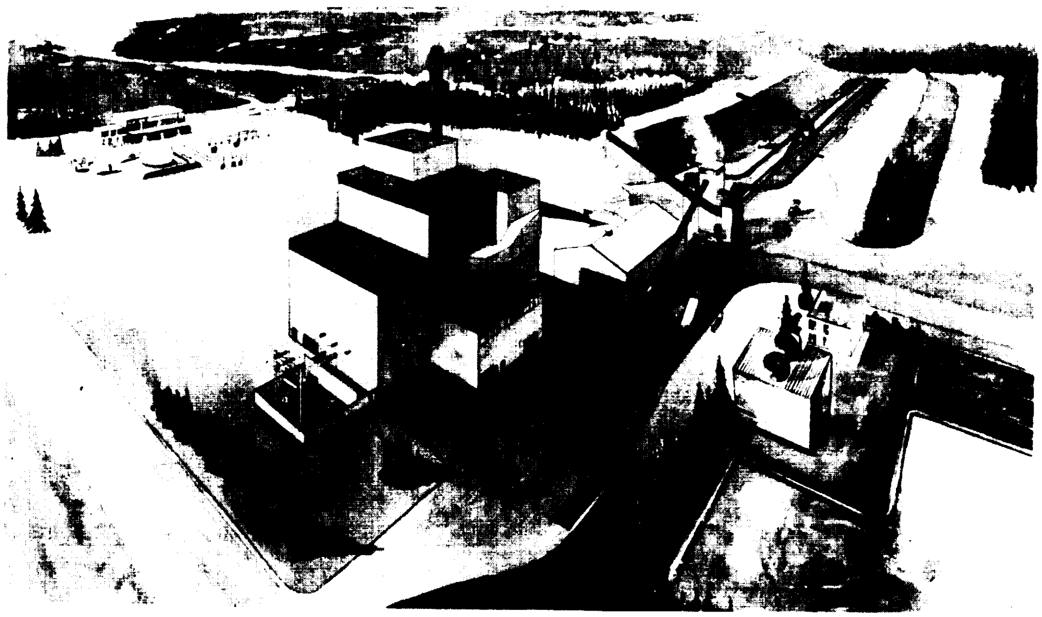
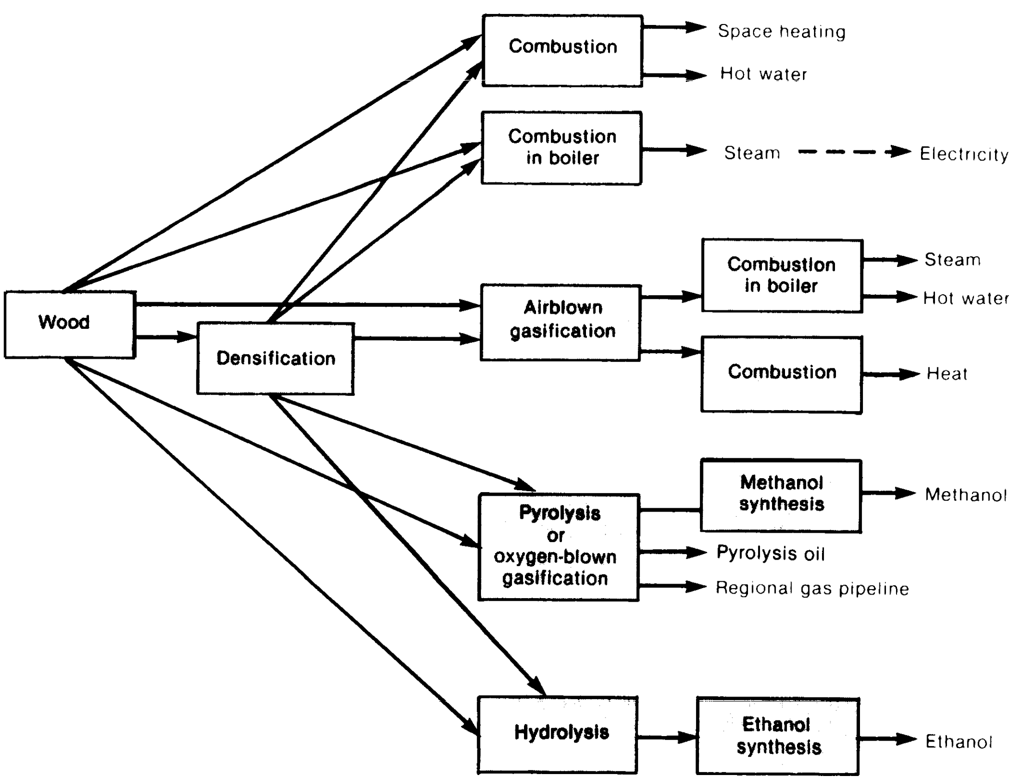


Photo credit Daverman Associates Inc

Proposed electric generating plant fired with waste wood

Figure 14.—Conversion Processes for Wood



SOURCE Off Ice of Technology Assessment

For each of these uses, the wood can be used directly or it can be pelletized first. Pelletization reduces the moisture content and improves the solid fuel handling characteristics. This enables pellets to be transported longer distances and easily ground to a small particle size for relatively automatic operation of facilities. These can be important features for some users.

Direct combustion of wood is possible with commercially available technology. The efficiency and flexibility of direct combustion can be Improved, however, through R&D into wood drying and the chemistry of combustion for the development of advanced drying and combustion units.

The efficiency of home heating units varies widely, and consumers need more information on the performance of available units as well as on their safe installation and operation. Airtight stoves generally achieve more even heating than other units by restricting the combust ion air to slow down combustion and cut excess heat loss out the flue, but w i t h present technology this also leads to increased emission of tars and particulates. These emissions represent unburned biomass, so their escape from the combustion chamber lowers the stove's efficiency below what otherwise would be achieved with airtight stoves. There is no fundamental reason, however, why relatively high-efficiency units with low emissions cannot be developed and mass produced for home heating at reasonable costs.

Reliable, high-efficiency, airblown gasifiers could become commercially available i n as few as 2 to 5 years (figure 15). These gasifiers could provide a more economic means (than direct combustion) of converting existing oil-gas boilers to wood while allowing the flexibility to return to oil or natural gas without additional cost if wood is temporarily in short supply and the oil or gas is available. Furthermore, they could be used for process heat— an option not currently practical for direct combustion.

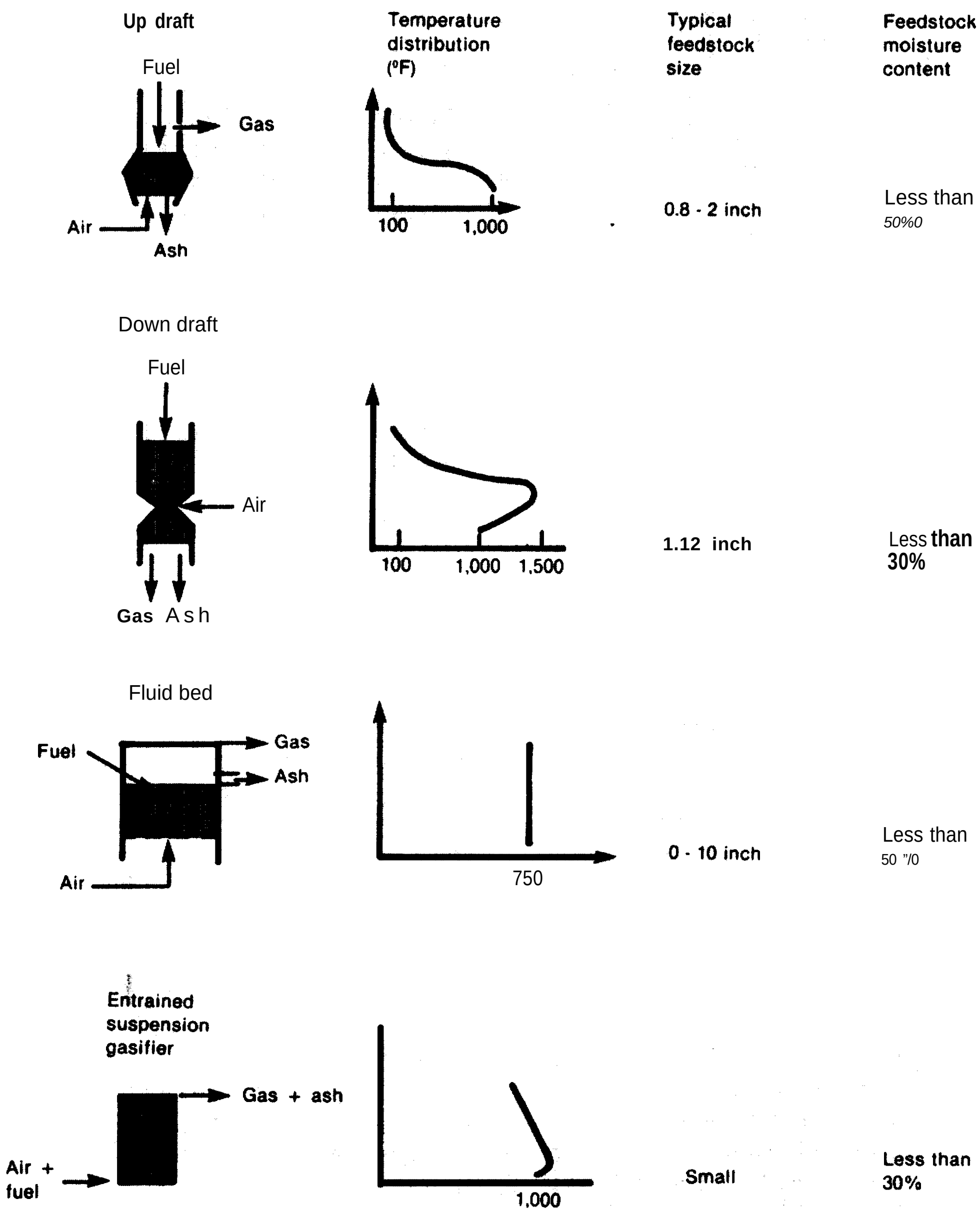
Facilities for converting wood to ethanol and methanol could be constructed immediately although none exists in the United States. The methanol probably would cost about the same (per Btu) as ethanol derived from grains and sugar crops (see "Alcohol Fuels"). The ethanol, however, would be more expensive than ethanol from either grains or more developed wood-to-ethanol processes I f development is given adequate support, advanced commercial wood-to-ethanol facilities could be available by the mid- to late 1980's Wood-based methanol is likely to be more expensive than methanol from coal, but it may be comparable in price to the more expensive synthetic liquid fuels from fossil sources that can be used as gasoline substitutes.

Direct combustion or gasification of wood can displace more oil or natural gas per ton of wood than conversion to synthetic liquid fuels except when the liquid fuel is used as an octane-boosting additive to gasoline.* I n order to achieve wood energy's large oil displacement potent i a 1, however, some liquid fuels product ion probably will be necessary because they can be transported more economically than sol id wood fuels and because they are in demand as transportation fuels.

Pyrolytic oil from wood could be used as a boiler fuel. It would compete, however, with direct combustion and airblown gasification that probably can supply industrial heat needs at much lower costs. Consequently, pyrolytic oil is likely to be limited to users who are willing to pay a premium for fully automatic boiler operation until pyrolysis becomes more economical.

* See 'Energy Balances for Alcohol Fuels'' under "Conversion Technologies and End Use' [illegible]

Figure 1 S.—Select Airblown Gasifier Types[a]



[a]Note that other schemes such as moving grate gasifier also exist.

SOURCE: From R. Overend, "Gasification - An Overview," *Retrofit '79, Proceedings of a Workshop on Air Gasification*, Seattle, Wash., SERI/TP-49-183, Feb. 2, 1979.

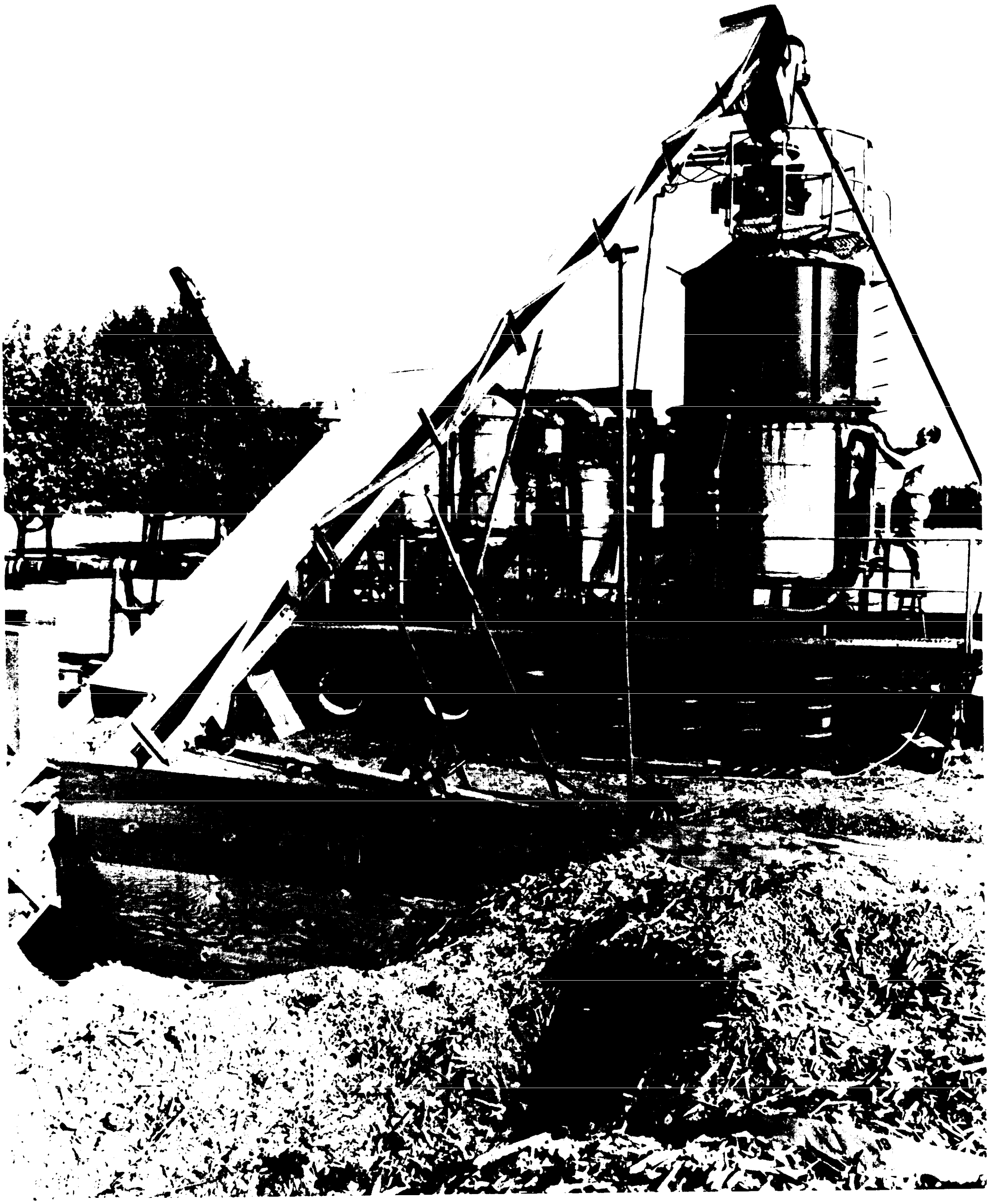


Photo credit Department of Energy Schneider

A prototype downdraft, airblown gasifier using wood chips as the fuel

Economics

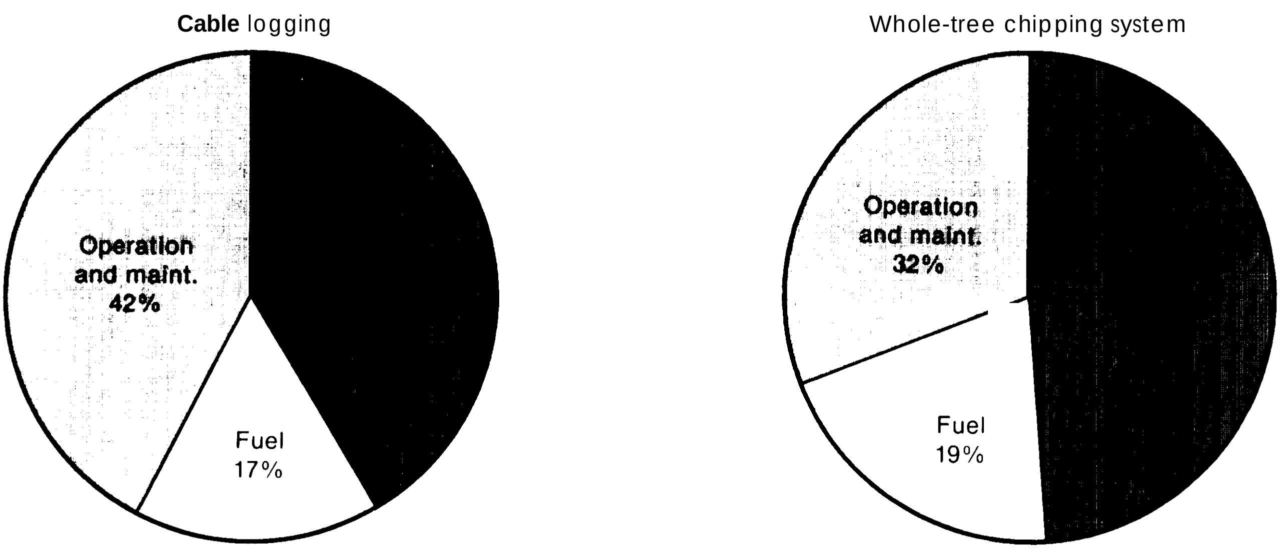
In an effort to reduce their energy costs, energy consumers will bid up the price of fuelwood, taking into account its relative inconvenience, until it is priced comparably with premium fuels. A rising fuelwood price will cover greater harvesting costs and thus make it profitable to use a greater fraction of low-quality timber resources for energy (figure 16).

At least two important caveats may cloud the economic picture for wood energy (see below), but first it is important to understand the opportunities. I n addition to the price incentive mentioned above, the use and market value of fuelwood will increase due to an economic synergy between wood energy and primary forest products (mainly lumber, pulp, and paper). As primary product markets expand, so will the availability and use of fuelwood. First, why should primary product markets be expected to expand and then, why does this stimulate wood energy?

Production and consumption of primary wood products will expand as the economy grows and as users of petroleum products and other forms of energy adjust to unusual price inflation. Use of wood construction materials in building retrofits and in energy-efficient new construction will expand (and their prices will rise) as the stock of buildings is upgraded to control rising costs for cooling and heating. Similarly, the use and price of wood and paper products will rise as they are substituted for energy-intensive al urn inure and plastic.

When the production of primary products expands, it creates a supply and a demand for wood energy. Today, about 45 to 55 percent of the energy used to process lumber, pulp, paper, etc., comes from wood wastes collected at mills and from combustion processes used to recover paper-pulping chemicals. Because no additional harvesting and transportation costs are incurred, this is an extremely low-cost energy source. Although some of what are presently considered mill wastes will be used for primary products in the future, the expected expansion of primary product production will certainly increase the amount of low-cost energy obtainable directly from wood milling activities.

Figure 16. —Cost Breakdown for Timber Harvest



SOURCE: Off Ice of Technology Assessment

A different type of synergy exists in silviculture. Rising prices for primary forest products will encourage more intensive management of commercial forestland. Stands will be harvested for mill feedstocks that otherwise would be left standing for a much longer period. Less productive species and stands, which have been degraded by selective harvesting in the past, will be clear cut in order to replant more productive stands. Slash will be removed from logging areas and the sites replanted with species that will hasten regeneration and maximize its value. Also, standing timber will be thinned more often in order to maximize light, moisture, and nutrients available to preferred trees. All of these practices will make residues available immediately and will eventually increase milling wastes as energy byproducts from primary production.

At the same time, rising fuelwood prices make silvicultural residues more valuable as fuel. From the viewpoint of primary product economics, income from the sale of residues lowers the net costs of silviculture, making it more profitable to increase wood productivity per acre. However, for this to be significant, owners of forestland must take a long-term perspective. They must want to increase production of wood that may not be harvested for another 30 years or more.

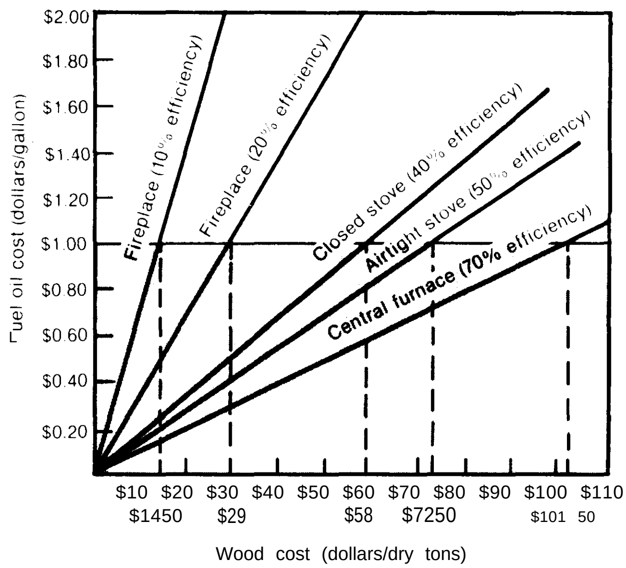
If the long view is not taken, and demand for all wood products rises without proper management, then this very bright picture of synergy at the mill and in the forest will be clouded as available wood resources are stretched to meet all demands. The main problem arises for fuelwood users outside of the primary product industry who cannot shift into and out of mill

feedstocks and forest products as technology and other economic conditions change. For them, prices may prove to be highly erratic and, as the technology for making particle board and other reconstituted wood fiber products develops, it is possible that they will not be able to compete with mills even for the lowest grades of greenwood.

Nevertheless, while a large inventory of fuel-grade timber exists, wood energy will be highly competitive in forested regions of the country. This conclusion is based on estimated total costs to final consumers of wood energy, assuming a reasonable range for wood costs. Increased supplies of fuelwood above the present 1.5-Quad/yr level can be obtained in limited quantities for as low as $20/dry ton in parts of New England. ' A more conservative cost estimate would be the current cost of pulpwood, around $40/dry ton, which fuel users may be forced to pay in competition with pulpmills even though fuelwood can be of much lower quality. [7]A still more conservative estimate comes from the cost of collecting logging residues in the Northwest, around $60/dry ton to collect residues left after conventional logging. '

As use increases, delivered prices will rise, to provide greater economic incentives to suppliers, but economic conditions in the foreseeable future suggest that wood energy users could afford to pay up to $90/dry ton of wood delivered (figure 17), At the latter price, total costs of process steam or space heat, in the most attractive industrial applications, can be less than $6/million Btu. At $0.90/gal, the cost of #2 fuel oil alone is $6.50/million Btu. Such a simple cost comparison is no substitute for a detailed, site-specific cost analysis, when actual investments in wood or other fuels are being compared, but this broad range of realistic and attractive fuelwood prices, coupled with the large resource base, clearly indicates a substantial economic opportunity,

Figure 17.— Fuel Cost Comparison Between Wood and Fuel Oil[a]



[a]Assumes oil burned with 80% efficiency

SOURCE Office of Technology Assessment

Four cost components must be considered in greater detail in specific locations:

- the stump age fee paid to landowners for permission to harvest trees,
- tree harvesting,
- transportation, and
- conversion to useful energy products.

Each component corresponds to a stage in the production process. The third and fourth stages may be repeated if intermediate fuel processing is included.

Stumpage fees and harvesting costs are closely related. The less expensive it is to harvest wood (and to bring it to a loading site for transportation), the more a logger will be willing to pay for the right to harvest a particular woodlot (the stumpage fee), and vice versa. The stumpage fee also depends on a series of additional factors that woodlot owners may consider in deciding when their trees will be cut, if ever. Understandably, owners will not negotiate stumpage fees that do not compensate for private esthetic, recreational, or ecological benefits lost in harvesting.

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[6]Charles Hewitt *The Availability of Wood for a 50-MW Wood-Fired Power Plant in Northern Vermont* (Hanover, N.H. Resources Policy Center, Thayer School of Engineering, Dartmouth College 19781, DSD No 114

Private communication with U S Forest Service, Forest Resources Economics Research Staff 1980

[8]Kip Howlett, op cit

Woodlot owners also follow market price quotations and, unless they are forced to sell in order to earn necessary income, they can easily wait for high prices.

This option — to wait— creates price uncertainties for potential wood users. Furthermore, fluctuations in paper and pulp markets can drive local wood prices up or down sharply and unpredictably. When prices are extremely high, fuelwood users suffer. When they are extremely low, loggers suffer. As a result, one or both of these actors in the wood fuel cycle may not invest in the necessary equipment without long-term contracts that bind wood lot owners to sell needed feedstocks. In any case, the prices and costs quoted above, in the range of $20 to $60/dry ton, indicate expected average market conditions.

Local conditions have been emphasized because wood has a low energy density compared to fossil fuels, and thus transportation costs per million Btu are relatively high. Greenwood (about **50** percent moisture) has about 8 million Btu/ton, bituminous coal about 23 million Btu/ton, and crude oil about 36 million Btu/ton. As a solid, wood also is difficult to handle compared to gases and liquids, although it can be converted into these forms.

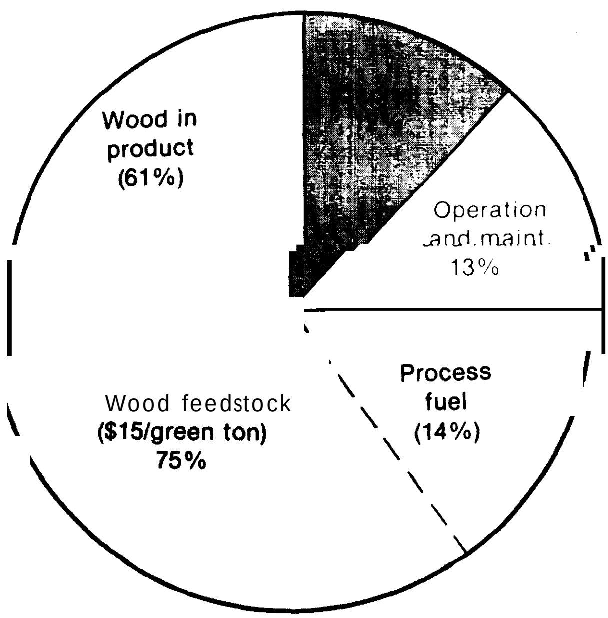
As a rule of thumb, it costs about $0.10/ton-mile to transport wood So, transport of greenwood 200 miles adds **$20** ‘ton to the price of wood and about $2.50/million Btu to the fuel cost. In other words, it pays for processors, who would upgrade wood into a preferred fuel, or for final users to locate near producing forests. High transportation costs also mean that local wood markets are somewhat isolated and hence local price fluctuations are not easily moderated by regional or national adjustments.

After wood has been removed from the forest for fuel, it may be transported to end-use sites, where it is converted directly into useful energy products. Or, it may be transported to sites where it is converted or upgraded to a higher quality, intermediate form of energy. Upgrading is considered first, followed by direct conversion.

Among the intermediate or upgraded forms of wood energy, the most likely to be economical are wood pellets, methanol, and electricity Intermediate-Btu gas (see below) is not considered as an intermediate product because it is practical only when the gasifier is directly attached to the final combustor. Consequently, it is practically indistinguishable from direct conversion, except that it can be used for more end uses. Unlike the greenwood feedstock from which they are made, pellets, methanol, or electricity may be transported hundreds of miles before final conversion into heat, steam, light, or mechanical motion

Pellets are an ideal wood feedstock for gasifiers or final combustors because they permit maximum automation in equipment and maximum conversion efficiency for the final user Their uniform shape and low water content also reduce handling and transportation costs Offsetting these advantages are pelletizing costs, including process energy, equipment, labor, etc. (figure 18) Assuming wood provides process heat and that greenwood costs about **$15** ‘ton ($2.00/million Btu), then the pellets

Figure 18. —Cost Shares of Wood Pellets



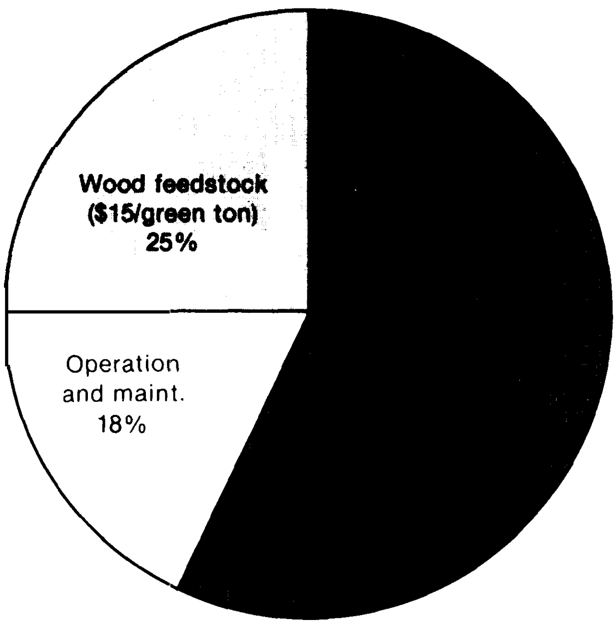
SOURCE Office of Technology Assessment

could cost about $46/ton ($2.90/million Btu). This added cost of about 50 percent **must be compared to the resulting savings** in transportation and to the value of automation and reliability to the end user.

Methanol is the next most expensive intermediate fuel product, with costs in a range from $0.75 to $1 .10/gal ($11 .80 to $1 7.30/million Btu) when wood is $30/dry ton and for a 40-million-gal/yr plant (roughly equivalent to a 60-MW electric power station) (figure 19). This size facility would also produce electricity from wood, in a cost range 50 to 70 mills/kWh ($14.60 to $20.50/million Btu), the most expensive form of wood energy that is likely to be considered (figure 20). In both cases, methanol and electricity, the economic viability of wood energy depends mainly on the cost of fossil and nuclear alternatives. Because the latter can take advantage of significant economies of scale, wood will be most competitive where local conditions or the need for rapid construction preclude these alternatives.

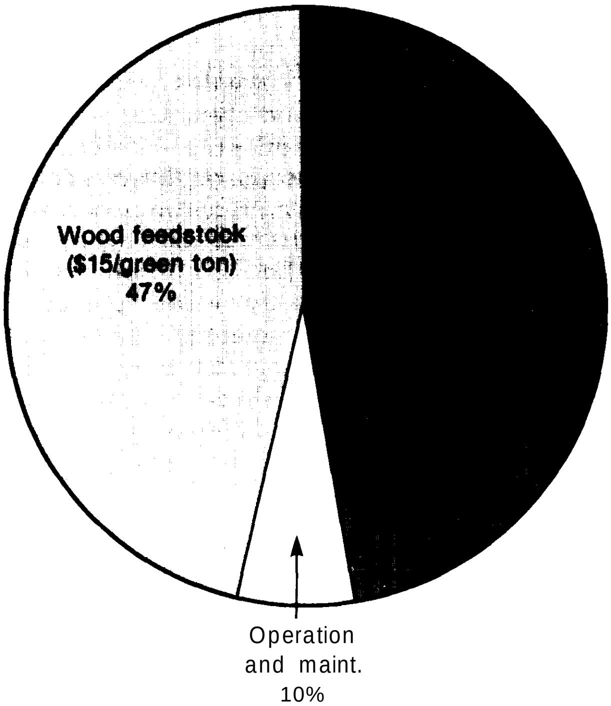
The economic attractiveness of intermediate conversion is also region-specific due to competition with gasifiers and combusters for limited greenwood feedstocks. The latter may require the entire local output of the forests and hence intermediate conversion processes may be priced out of the feedstock market.

Figure 19. —Cost Shares of Wood Methanol



SOURCE Off Ice of Technology Assessment

Figure 20.—Cost Shares of Wood Electricity



SOURCE Office of Technology Assessment

From the viewpoint of end users outside the forest products industry, the relative cost of energy from greenwood or air-dried wood depends on the amount of energy used. For facilities using more than the equivalent of 1,000 dry ton/d of wood, coal is likely to be less expensive due to economies of scale in mining and transportation. For facilities smaller than 1,000 dry ton/d, but larger than very small industrial/commercial facilities, either wood or coal may be preferred depending on their relative market prices, which vary with location. Finally, for very small-scale users, natural gas or fuel oil may be preferred mainly for their convenience.

The industrial user has a significant advantage if operations run more or less 24 hours a day (that is, there is a high load factor). This allows capital costs, which may be two to three times as great as for oil or gas, to be spread over the greatest number of Btu. The space heating user, on the other hand, may use combustion equipment only a third or a quarter of the time so real capital costs are three to four times larger The industrial user is also likely to convert wood into useful energy more efficiently because longer operating periods provide a greater incentive for superior maintenance and because trained mechanics are more likely to be available to do the job.

Table 4 illustrates a realistic range of costs for two generic commercial users, assuming a wood gasifier is added to an existing oil-fired boiler. Because the intermediate-Btu wood gas is almost a perfect substitute for oil, the relevant cost comparison is between the price of fuel oil and the total cost of the wood gas. The larger user may presently be using residual (#6) fuel oil, which could be purchased at around $0.60/gal during the first quarter of 1980 ($4.30/million Btu), while the smaller user may be using #2 fuel oil, which during the same period could be purchased at about $0,80/gal ($5.80/million Btu).[9] Prices for these petroleum-based fuels are likely to increase sharply in the future.

The costs of gasification equipment in table 4 apply to mass-produced, package units purchased for around $10,000/million Btu/hour capacity. The difference in capital cost between these two users is entirely due to different load factors. (It must be added that such equipment is not yet widely available in the market.) Energy from field-erected gasifiers (or boilers) can cost four to five times more (per unit output) than from package units.

As indicated in the table, the industrial user may be able to obtain wood energy at about two-thirds the cost to a commercial user, and such savings can be expected entirely on the basis of a higher load factor and superior conversion efficiency. They also more than offset the assumed difference in the cost of residual and #2 fuel oil, so wood conversion will be at least as attractive for the larger user.

Mass production has been achieved for another group of wood energy users. Wood stoves for home heating can be obtained at a reasonable price but total costs and benefits vary a great deal among users (see figure 17). For those who can obtain low-cost cordwood (often because they collect it themselves), who do not mind filling the firebox, cleaning out ashes, and having the uneven heat of inexpensive wood stoves, wood home heating can be very economical. Wood stoves a l so serve as an important hedge against rapid price inflation of oil and natural gas.

At all four stages of production, cost estimation must be done very carefully and, in many locations, uncertainties may be too great to justify investment. Besides the reasons already mentioned, uncertainties arise because fuelwood markets have not yet developed and so producers cannot be sure that users will be there to buy, or users cannot be sure that producers will be there to sell. Even though wood has always been used for energy, the future

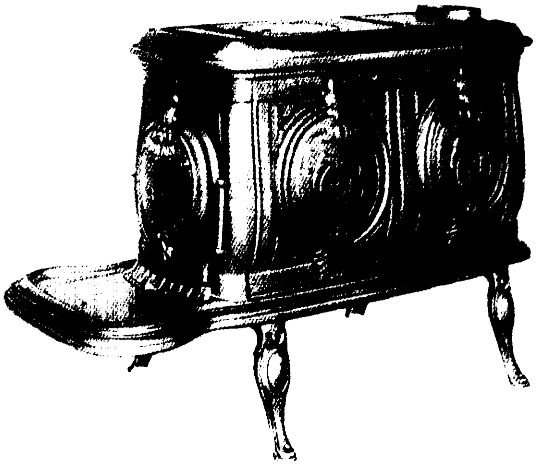
[9]Fuel oil prices from Weekly Petroleum Status Report, Mar. 14, 1980, and Monthly Energy Review, February 1980, Energy Information Administration.

Table 4.—illustrative Wood Energy Costs (per million Btu)

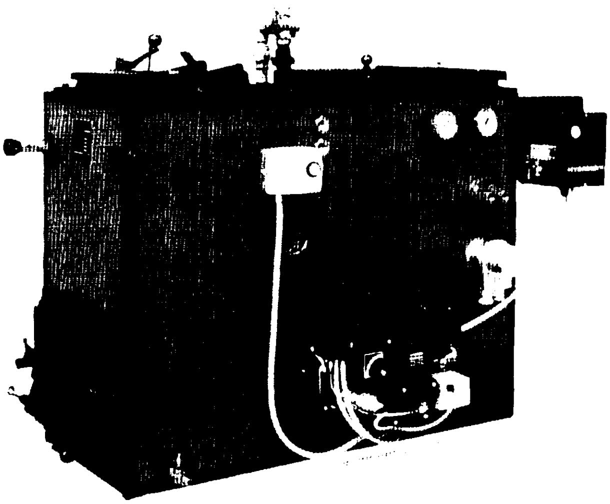
	Total cost	Delivered feed stock cost ($40/dry ton)	Capital cost	Operating cost
Medium-size, industrial user, **Greenwood** use: 250 dry ton/d Load factor: 90% Energy efficiency: 85°/0	$3.60	$2.95	$0.40	**$0.25**
Smaller, commercial user Greenwood use: 30 dry ton/d Load factor: 25% Energy efficiency: 700/0	5.50	3.60	1.40	0.50

SOURCE Off Ice of Technology Assessment

Representative Wood Stoves for Home Heating



The box stove, a successor to the potbelly



Wood-fired furnace for heat and hot water

prospects discussed here amount to a new industry that may appear highly speculative just because it is new.

Potential wood energy users must also deal with the performance uncertainties inherent in new lines of conversion equipment. They are likely to have grown accustomed to the automated convenience of liquid and gaseous fuel systems so that wood energy would appear to be inconvenient and unreliable. The forest products industry is the exception in this regard. With its working knowledge of wood harvesting and conversion techniques, it is in an excel lent position to capitalize on the economic opportunities,

From the viewpoint of society as a whole, the final uncertainty in wood is the willingness or unwillingness of energy users and their bankers to make larger investments in conversion equipment than they have made in the past. In effect, substituting wood for oil and gas involves the substitution of capital as well. Consequently, the further into the future energy users and their bankers can see, the more fuel savings will effectively offset higher initial investment costs and the more attractive wood energy will appear to be. From the viewpoint of trying to achieve a maximum substitution for oil, however, private market decisions may very well prove too shortsighted and, as a result, wood energy may not expand as rapidly as it could.

Environmental Effects

The major environmental issues arising from the possibility of substantially increased wood use for energy are the potential for both positive and negative effects on America's forests and the pollution potential of wood-to-energy conversion processes.

The rapidly rising use of wood for fuel in New England and elsewhere has raised both hopes and fears for the future of America's forests Although a portion of these varying expectations probably can be explained by differing perspectives about the role of the forest as both a material and environmental resource, the remainder may be explained by alternative visions of what is actually likely to take place in the forest —whether, on the one hand a "scenario" of careful management unfolds, or whether a pattern of shortsighted and destructive exploitation emerges Unfortunately, the available information permits at best an educated guess at how the landowners, integrated forest product companies, small-scale loggers, regulatory agencies, and other groups who affect forest management practices will respond to an increased demand for wood as an energy resource This, in turn, prohibits a precise assessment of the environmental effects of an Increased demand. In spite of this limitation, however, it is possible to identify likely problem areas by, first, identifying the environmental effects associated with **specific possible outcomes of an increased wood energy demand and, second, examining the** available evidence (existing economic and regulatory incentives, current management practices) that wood suppliers will or will not practice good environmental management.

Potential Effects of Increased Fuelwood Demand

The expected changes in forest management caused by an increase in demand for fuelwood — more intensive management, more complete removal of biomass, increased use of improvement cuts and conversions of low-quality stands, increased harvesting of non-commercial timber stands — will have profound environmental effects on forestland. Some of these effects are strongly positive. Where good management is not practiced, adverse effects could be especially severe.

The general lack of data on environmental conditions on forestland in the United States and the complexity of the forest system make it virtually impossible to predict precisely what effects, both positive and negative, might occur if as many as 10 Quads/yr of wood were removed for energy. Improvements in the knowledge of soil and other environmental parameters, current logging practices, and the long-term effects on forest soils and productivity of a high rate of biomass removal would enhance the ability to predict the environmental effects of a wood energy boom.

The major environmental issues associated with the expected changes in forest management and the new financial incentives to obtain wood for energy are:

- possible soil depletion from intensive management procedures,
- decrease in logging pressures on some environmentally valuable or fragile forestlands that also have valuable timber resources,
- changed forest "character,"
- intensification of adverse effects of poor management,
- damage to marginal lands, including deforestation,
- wood poaching, and
- problems of small-scale harvesting.

Soil Depletion

The shorter rotation times and greater removal of biomass inherent under "intensified management" have raised fears of long-term depletion of nutrients and organic matter from forest soils and subsequent declines in forest productivity.

The potential for sustaining these effects is not well understood, although several studies have demonstrated that long-term nutrient depletion may occur after whole-tree harvesting.[10] Forestry experts do agree that soil depletion effects should be a matter of concern under some conditions of intensive management, and conceivably could become a constraint on the intensity of practices used and on the selection of sites and tree species to incorporate into this type of management, Although nutrient depletion may be alleviated by the use of fertilizers, these may not work well unless the deficiency is fully understood, Also, fertilizer use does not address potential problems associated with depletion of organic matter, which is often characterized as playing a critical role in maintaining the productive potential of forest soil.[11] In some cases, fertilizers used to increase growth will aggravate nutrient depletion problems by decreasing the forest's supply of other nutrients.

In all but extreme cases, any declines in forest productivity* would occur slowly. Thus, if cause-and-effect relationships between alternative management practices and any soil depletion effects can be established, it should be possible to deal with any long-term productivity problems by monitoring soil [and other) conditions and adjusting management strategies in response to changing conditions, However, improving the state of knowledge enough to enable detection of subtle productivity deterioration and to allow necessary adjustments may not be easy. Aside from the complicating effects of other forces that act on forest productivity (such as acid rainfall), the cause-and-effect relationships are likely to be both subtle and extremely site specific. Although it is not now possible to predict the importance and extent of any future productivity problems associated with more intensive forest management, any problems that do occur may be difficult to regulate.

Relief of Logging Pressures

Rising demand for lumber creates significant pressure at both ends of the logging spectrum — there is greater use of low-quality wood in chip board and other forms of "manufactured" lumber, and greater pressure to harvest high-quality timber from stands that also have significant esthetic, recreational, and ecological value. It is widely felt among foresters that the demand for wood energy could lead to intensified management of forests (because the availability of a market for thinnings and logging residues helps to pay for management costs) and, eventually, to greater yields of high-quality timber from commercial forestlands. This expected increase in high-quality timber would then be expected to relieve the pressure to harvest scenic old-growth stands and other stands that have both high nontimber values and valuable standing timber.

This potential benefit of an increase in intensive management (spurred on by a rising wood energy demand) appears to be plausible. OTA estimates that placing 200 million acres of commercial forestland into intensive management (full stocking, thinnings every 10 years, 30- to 40-year rotations) could allow wood energy use to reach 10 Quads annually while the availability of wood for nonenergy products might double its 1979 value. Alternatively, the same result might be achieved by using less intensive management on a larger acreage. The nature of any actual benefits, however, is dependent on the following considerations:

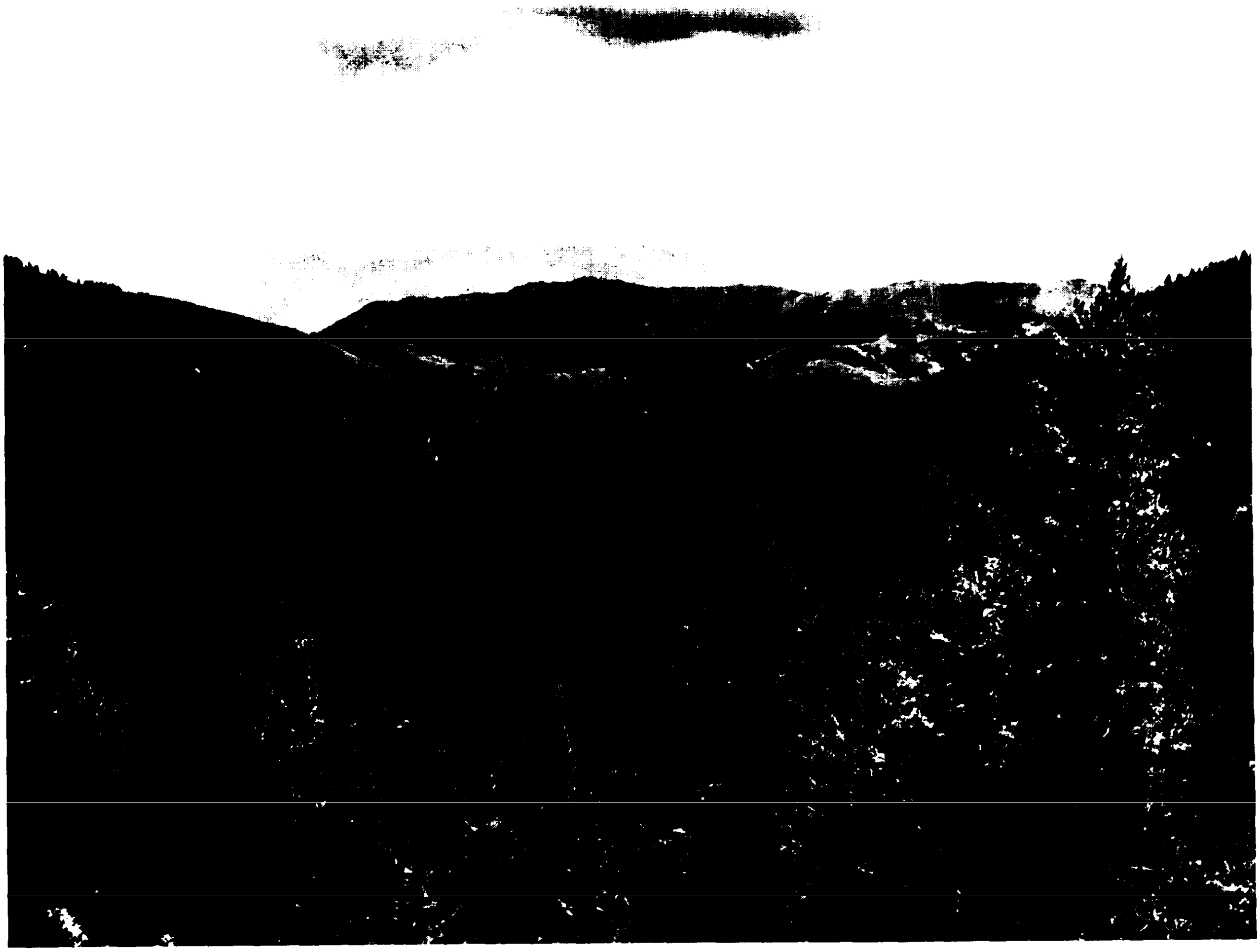
- Major effects on the availability of high-quality timber probably would not occur for a number of years. Some additional high-quality wood might be available immediately from stand conversions and harvest of noncommercial timber, and some in about 20 years from timber growth in stands that required only thinning for stand improvement. The quantities would not peak, however, before about 30 to 40 years as stands that had been cleared and replanted began to

[10] For example, see C. J. High and S. E. Knight, "Environmental Impact of Harvesting Non-Commercial Wood for Energy: Research Problems," Thayer School of Engineering, Dartmouth College paper DSD No. 101, October 1977; also C. G. Wells and J. R. Jorgenson, "Effect of Intensive Harvesting on Nutrient Supply and Sustained Productivity," *Proceedings: Impact of Intensive Harvesting on Forest Nutrient Cycling* (Syracuse, N.Y.: State of New York, Aug. 13-16, 1979).

[11] E. H. White and A. E. Harvey, "Modification of Intensive Management Practices to Protect Forest Nutrient Cycles," in *Proceedings: Impact of Intensive Harvesting on Forest Nutrient Cycling*, op. cit.

[12] C. G. Wells and J. R. Jorgenson, op. cit.

*Averaged over the different growth stages of a stand



reach harvesting age. By this time, most of the old-growth stands accessible to logging already may have been harvested, although significant benefits from reducing logging pressures on other valuable or fragile lands would still be available.

- Although the increased availability of high-quality timber might negate arguments that these valuable or fragile stands **must** be cut to provide sufficient wood to meet demand, there is no guarantee that the wood made available from intensified management will be less expensive than that obtainable from these stands, and economic pressure to harvest them might continue.

Forest Character

A widespread shift to intensified management, with increased thinning, whole-tree harvesting, and residue collection will create a very different kind of forest from today's, both visually and ecologically.

Visually, the affected forest areas will be more open and parklike. The trees, although fewer in number, will be straighter and have thicker trunks. Downed, dead, and diseased trees and logging slash generally will be absent,

Both the wildlife mix and the types of trees will be significantly different. The type of trees grown will be more controlled, and the species diversity within individual stands will be reduced. Trees with little commercial value* may be eliminated, although areas in multiple use management would retain species valuable to sustaining wildlife, The wildlife mix itself will reflect the new, more open conditions. Birds and small animals that rely on slash and dead and dying trees for their habitat will be reduced in number, to be replaced by species better adapted to the new conditions.

The extent to which wildlife values may suffer will depend very much on the type of harvesting practiced, the extent to which replanting measures control the growth of vegetation valuable to wildlife, the presence of valuable species that cannot tolerate intensive management, and the total acreage affected and its distribution. If mechanical and chemical brush controls are used on newly cut areas, if clearcuts are very large in area, or if large pockets of forest are not spared, then wildlife diversity and numbers may be degraded. Otherwise, the species mix may change but the wildlife population should be as diverse and numerous as in the original forest.

Because most of the present forests are the offspring of past exploitation and "high grading" (the selective removal of only valuable trees) and are far from pristine ecosystems, the ecological implications of these changes should not automatically be considered as negative. This is especially the case where the diversity of forest ownership prevents extremely large contiguous areas from being placed in single species management (monoculture).

Managed forests are often described as "healthier" forests than the largely unmanaged forests found in the East. This may be a fair statement from the perspective of measurable economic worth; timber growth will be enhanced, the population of game animals will increase, damage-causing agents such as bark beetles that reside in slash or dead and dying trees will be reduced, and the incidence of forest fires might decrease. However, the effects of intensive management on other components of forest "health" such as long-term stability and resistance to disease epidemics are not as well understood and may be negative in some cases. * Also, although large portions of the public may approve of the changes in forest appearance and character inherent in an increase in forest management, policymakers should still expect substantial opposition to these changes, especially considering the uncertainties about the potential for long-term soil and productivity effects.

*The types of species with commercial value will change as new methods appear for using low quality wood, and as the availability of (currently defined) high-quality timber changes.

Poor Management

Although the long-range economic goals of intensive management provide an incentive against poor environmental practices, careless logging and regeneration practices will still occur on a portion of the managed sites. Poor management may be practiced on an equal or smaller proportion of sites than would have been the case without an expansion of wood-for-energy, but the effects of poor management may be considerably aggravated with such an expansion because:

- more acreage will be logged each year,
- most affected sites will have fewer years to recover before they are logged again, and
- removal of maximum biomass and the subsequent soil depletion may reduce the sites' ability to recover.

The major damages associated with poor management include:

- **Erosion** stemming from harvesting on steep slopes with unstable soils (leading to slumps, landslides, other mass soil movement), careless log skidding and road-building (leading to soil damage through compaction or exposure of mineral soils), overintensive land preparation for new planting, harvesting under wet conditions (leading to excessive soil compaction), and land disturbance during residue removal. Overintensive land preparation for replanting appears to be a major problem with forest products industry operations

*See vol. II for a brief discussion of this issue in the Southeast.[13] **Erosion is likely to intensify soil depletion effects.**

- **Adverse effects on water quality** from erosion, failure to maintain stream buffer zones, crossing of stream channels by machines.
- **Esthetic damage,** especially when basic management measures (buffer strips, size limitations on clear-cut areas, avoidance of recreational areas, use of shelterwood harvesting– leaving a protective canopy of trees —when scenic vistas may be disturbed) are ignored.
- **Loss of or damage to valuable ecosystems,** recreational land, wilderness area, etc.
- **Flooding danger** when too high a percentage of land in a watershed is cut simultaneously.

Damage to Marginal Lands

As the price of wood fuel grows, there will be increasing incentive to harvest poor-quality stands on marginal lands with nutrient deficiencies, thin soils, and poor climatic conditions— lands where there is little potential for future high-quality timber growth, The environmental impacts of logging these lands are likely to be large, because the damage potential is higher (greater risk of nutrient depletion, erosion, etc.) and the likelihood of mismanagement is greater (because the logger will not have a continuing relationship with the land). Much of this land, although "poor" from the standpoint of commercial productivity, is valuable for its esthetic and recreational values, watershed protection, and other forest values. These values may be lost or compromised by logging on sites where forest regeneration may be a problem – for example, on sites in the arid Southwest. Permanent loss of these forest values is likely to be more important than any immediate logging impacts, especially because the immediate impacts can be reduced by good logging practices. These dangers are somewhat tempered, however, by the Federal ownership of much of the most fragile lands.

[13] *Environmental Implications of Trends in Agriculture and Silviculture, Volume II, Environmental Effects of Trends* (Washington, D.C.: Environmental Protection Agency, December 1978), EPA-600/3-78-102

Poaching

A rising price for wood fuel will also— inevitably — lead to an increase in illegal harvesting. There are no data on such activities today, although stories abound about disappearances of walnut and redwood trees and other high-quality timber. However, extensive illegal mining of coal on public and private lands has occurred, despite the substantial length of time it takes to uncover and mine a coal seam. The rapidity with which trees can be cut and removed from a site appears to guarantee a strong danger of wood piracy with, certainly, a disregard for environmental values. The danger will be especially great in areas where a reliable and competitive retail supply infrastructure is not established.

Small-Scale Harvesting Problems

Harvesting by individuals, many of them inexperienced in logging and silviculture in

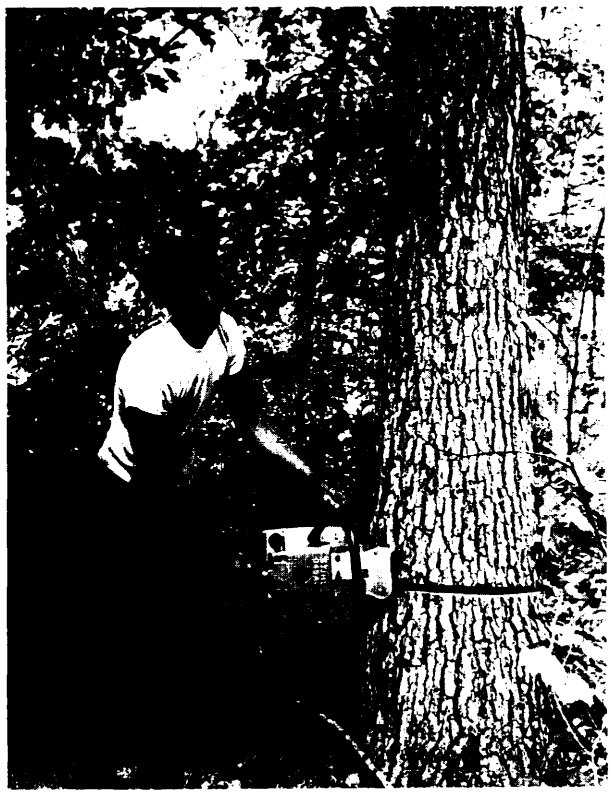


Photo credit USDA. Bill Marr

Wood harvesting by individuals will accompany an increase in the use of wood for home heating general, will also accompany any substantial increase in wood use for residential heating. If done properly, this type of harvesting on small woodlots has the potential to improve timber values in a manner similar to that obtained by intensive management practiced by the forest products industry. Where the woodlot is too small to sustain a continuous yield or the individual lacks the proper knowledge of which trees to cut or how to cut them, damage to the forest and a significant rise in forestry-related accidents will occur. Although, again, no reliable data exist, foresters are beginning to see an acceleration of these problems that may coincide with the remarkable growth in residential wood stoves and furnaces. A continued escalation of such problems appears to be virtually inevitable unless substantive measures are taken to provide small woodlot owners with easy access to management help. Although some access is available through Federal-State cooperative programs, this effort currently falls short of what is needed.

Good Forest Management— How Likely Is It?

The actual environmental effects of a greatly increased harvest of wood for energy will depend in large measure on whether or not wood suppliers adopt environmentally sound harvesting and regeneration techniques. At present there is no guarantee that a "careful management" strategy will be followed.

Existing economic incentives to practice environmentally sound management are mixed. There are a variety of positive incentives to use sound harvesting procedures and to prefer higher quality sites– if they are available. These incentives include lower logging costs on flatter— and thus less erosive— lands, the timber improvement potential inherent in properly managed harvesting on high-quality lands, and the potential for loss of significant recreational and esthetic values — and subsequent loss in overall land value— if logging is mismanaged or conducted on vulnerable land, In many situations, however, these incentives may be canceled. Although considerable high-quality forest acreage is available on a national and regional basis, local variations in land availability may expose vulnerable lands to exploitation —especially because wood is usually considerably less expensive if obtained within a small radius of the user. The long time period needed to recoup the full benefits of good management as well as the tendency of some of the benefits (such as prevention of damage to streams) to accrue to adjacent landowners or the general public rather than to the investor also limit management incentives. Also, scientific understanding of the consequences of certain harvesting practices — especially whole-tree harvesting coupled with short rotations — is not complete, and proper economic tradeoffs cannot always be made. Finally, an unknown percentage of those involved in timber harvesting and woodlot management are more or less ignorant of proper management procedures and may not use — or may not have ready access to–trained foresters, This may become a particularly important problem if larger numbers of small landowners begin harvesting to satisfy their own residential wood requirements.

In addition to the mixed character of the economic signals leading to selection of forest management practices, regulatory incentives for controlling negative environmental impacts generally are weak in the United States. Most States, especially those in the East, have few strong statutes and guidelines for forest protection, insufficient manpower for proper enforcement, or both. Many State agencies focus most of their attention on forest fire prevention rather than on environmental management. Although section 208 of the Clean Water Act theoretically should promote control of erosion impacts from logging, implementation has been slow. Also, the complexity and site-specific nature of logging impacts add to the difficulty of creating and enforcing credible environmental protection regulations.

Assurances that environmentally sound logging practices are likely to be used cannot be obtained from knowledge of current operations, which is inadequate. Management practices of loggers on Federal lands are specified and supervised by the Forest Service and the practices of the big forest product companies are considered by many forestry professionals

– but *not* necessarily by environmental groups — to be reasonably sound (although there is little data to confirm this). However, the major potential for increased wood growth and production is in the East–the domain of the small private landowner and, especially in the North, of the small-scale logger Painfully few surveys are available on which to base generalizations about the environmental practices of these loggers and landowners. One small limited survey in Maine showed a virtually total failure to use simple environmental control measures such as water bars or reseeding erodible areas.[14] The importance or applicability to other States of such observations is unclear, but it seems fair to conclude that, given the absence of sufficient incentives for environmental controls, a real danger exists that the development of a substantial new wood fuel market may be accompanied by a considerable amount of tree harvesting that is not in accordance with environmentally sound management practices.

Conclusions

Increases in wood fuel demand may promote changes in forest management practices that offer some strong economic and environmental benefits. Other effects of these new management practices, as well as the effects of fuelwood harvesting on marginal sites, of an increase in small-scale logging for the residential market, and of the possible increase in tree "poach ing," may be strongly negative.

The effects of intensified management brought about by the increased value of low-quality wood as fuel cannot be considered unambiguously positive. Although increased availability of high-quality wood on the managed sites may decrease logging pressures in some forests that have high recreational, ecological, and esthetic value, the changed character of the managed forests may be objectionable to environmental groups. The adverse effects of bad management may be magnified by the shorter rotations and higher biomass removal rates. Long-term debilitation of some forest soils may be possible, and safeguards against such an effect might be difficult to implement,

Aside from these potential problems with intensified management, increased wood demand may promote practices that are unambiguously negative. The clearing of low-grade wood from marginal sites, made more attractive by high fuelwood prices, has a high potential for short-term erosion damage and, in some cases, failure of the forest to regenerate. Stealing of wood will become increasingly attractive and could be extraordinarily difficult to prevent. Also, the entry of thousands of homeowner-loggers into the logging community may bring an increase in poor harvesting practices as well as endanger personal safety and lives.

It is not possible with the current state of knowledge to assess accurately how these positive and negative aspects will balance each other. Many in the forestry community view wood energy as an opportunity to achieve better forest management and improved environmental conditions, and this potential certainly exists. On the other hand, the potential problems appear quite serious in light of the current weak economic and regulatory incentives for practicing good environmental management and the alarming lack of information about current logging practices.

Wood Conversion Impacts

The **conversion** of wood to heat and electricity and to liquid or gaseous fuels has potentially serious environmental effects, especially from the air pollution associated with the conversion processes.

Residential wood combustion may create serious particulate air pollution problems in areas where a high density of units is combined with occasional atmospheric inversions. Polycyclic organic matter (POM), species of which are known animal carcinogens, can comprise as much as a few percent of this particulate matter. Based on available emission data,

[14] "A Survey of Erosion and Sedimentation Problems Associated With Logging in Maine," Maine Land Use Regulatory Commission for the Maine Department of Environmental Protection, May 1979

POM emissions from wood stoves are likely to be far greater per Btu than from systems they would replace — residential oil or gas furnaces or, indirectly, fossil fuel powerplants. [15] The airtight stoves, with their slower rates of combustion, may aggravate the emission of these and other organic particulate as well as carbon monoxide (CO). On the other hand, emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from small wood stoves are quite low compared with the systems they replace.

Both the emissions and safety problems (see "Social Impacts") of wood stoves may be particularly noteworthy because the monitoring and regulation of millions of units are difficult, and proper operation depends on the actions of millions of individuals with greatly varying degrees of operating experience and understanding of the environmental and safety hazards involved.

Wood-fired combustion units of large size –for commercial, industrial, and even utility use— should present few pollution problems if equipped with efficient particulate controls. NO_x and SO, emissions are low; CO and organic emissions may be 10 times as high per Btu as emissions from large coal boilers but can be held to tolerable levels by maintaining good combustion efficiency;[16] and particulate emissions, while high, are control l able by electrostatic precipitators, wet scrubbers, and other available devices.

There has been very little actual experience with wood gasifiers so their emissions and environmental effects are somewhat speculative. Some early tests have indicated that emissions from a gasifier-boiler combination would be much lower than those from a similarly sized wood-fired boiler. [17] The raw, intermediate-Btu gas, however, could contain a number of toxic pollutants including ammonia, hydrogen sulfide and cyanide, and phenols and other aromatic compounds,[18] thus, leaks from the system could pose occupational hazards. Also, although there are no confirming data, the tar and oil byproducts of gasification may be carcinogenic. A fraction of these condense out of the system and may require careful handling.

Although such close-coupled, gasifier-boiler systems may have no water effluent aside from cooling water, gasifiers producing a higher Btu gas for transport off site or for methanol production (see "Alcohol Fuels") do produce an effluent from the water initially present in the feedstock or formed during the partial combustion accompanying gasification. This effluent — as well as the water from any wet scrubbers used for air cleaning or condensing tars and oils —will be high in oxygenated hydrocarbons and must be treated before disposal because of its high biological oxygen demand. Other potential pollutants include trace heavy metals, sulfides, and thiocyanates.[20] The condensed tars and oils will be either recycled to the gasifier or disposed of. The quantities collected will be considerably larger than in a close-coupled gasifier and will require similar careful handling.

Finally, in considering the environmental effects of wood energy, it must be remembered that to the extent that wood energy displaces oil, natural gas, or coal, it also reduces the environmental effects that occur in the production, transportation, and consumption of these fossil fuels. A comparative evaluation of these effects was not attempted in this study.

[15] Private communication with John O. Milliken, Environmental Protection Agency, Research Triangle Park, N.C., October 1979.

[16] E. H. Hall, et al., *Comparison of Fossil and Wood Fuels* (Washington, D.C.: Environmental Protection Agency, March 1976), EPA-600/2-76-056.

[17] "Source Test Report No. C-8-002-C, Source Test of Exhaust Gas From a Boiler Fired by Production Gas Generated From an Experimental Gasifier Unit Using Wood Chips for Fuel," State of California Air Resources Board, Stationary Source Control Division, March 1978.

[18] *Solar Program Assessment: Environmental Factors. Fuels From Biomass* (Washington, D.C.: Energy Research and Development Administration, March 1977), ERDA 77-47/7

[19] Private communication with Richard Doctor, Science Applications, Inc., November 1979.

[20] *Environmental Development Plan, Biomass Energy Systems* (Washington, D.C.: Department of Energy, September 1979), DOE/EDP-0032.

Social Impacts

The principal social impacts of the widespread use of wood energy are the effects on employment, on occupational health and safety, and on local tax revenues.

Wood energy harvesting and conversion are likely to be more labor intensive than fossil fuel alternatives. " For example, table 5 compares the average number of workers required to harvest the energy equivalent of 1 Quad/yr of wood with the mine labor needed to extract an equivalent amount of coal. As can be seen from this table, a wood-harvesting operation could require from 1.5 to 30 times more workers per Quad of fuel than a coal mining operation, depending on the wood harvesting and coal extraction methods. Assuming that between 5 and 10 Quads/yr of wood energy could be available, the increased employment in logging would be substantial. Alternatively, the use of wood to produce methanol would require 2,300 to 5,300 workers to harvest enough wood to produce 1 billion gal/yr of methanol (or approximately 0.08 Quad/y r), depending on the harvesting method. Associated employment effects for wood harvesting include the manufacture of logging or other equipment as well as the transportation of solid and liquid fuels.

[21] InterCroup Consulting Economists, Ltd , *Liquid Fuels From Renewable* Resources A *Feasibility Study* (Ottawa Government of Canada, Fisheries and Environment Services, 1978)

Table 5.—Labor Force Equivalents for Wood Harvesting and Coal Mining

	Ton/ workday	Total workers needed to produce 1 Quad/yr (thousands)
Logging residue		
Skidder, chipper	18-21	33-38
Cable, chipper.	18-19	35-40
Stand improvement		
Feller-buncher		
Skidder, chipper	16-18	38-43
Hand fell		
Cable, chip.	12-14	49-57
Coal mining		
Underground, East	8-17	11-21
Surface, West	65-130	2-3

SOURCE: James Bethel, et al., "Energy From Wood," OTA contractor report (1979),

Supplies of wood for residential heating could be associated with commercial-scale operations that would create jobs, or such supplies could involve owner or part-time harvesting that would either increase the amount of time spent procuring one's own energy or would add an additional source of family income.

Finally, wood energy use will mean more intensive forest management that will increase the demand for professional and technician-level foresters.[22] .

In addition to the jobs associated with harvesting and management, wood energy conversion will mean increased employment in the construction and operation of combustion and gasification facilities as well as the manufacture of facility equipment and residential units.

The use of wood in steam-generating plants also would create more jobs per Quad than the use of coal. Wood-fired boilers probably will continue to be smaller than 50 MWe, while new coal-fired powerplants typically will range from 200 to 1,200 MWe. As can be seen in table 6, from two to five times more construction workers are needed to install an energy equivalent capacity of 1 Quad/yr of wood fuel than are needed for the same capacity burning coal, although the actual number of workers would be less for both fuels because not all sites will

[22] Thomas H Ripley and R ichard L Doub, "Wood for Energy An Overview, " American Forests 84 16, October 1978

Table 6.—Jobs Associated With New Wood- and Coal. Fired Boilers

	Total workers needed for an energy equivalent of 1 Quad of fuel used per year (in thousands)	
	Peak construction	Operation
Wood[a].	65-80	8-15
Western coal[b].	17-34	2-3
Eastern coal[c].	16-32	2-3

[a] Assuming a fuel moisture content of 44 percent, 4,800 Btu/lb, and an 85-percent load factor.
[b] Assuming a heat value of 9,000 Btu/lb and a load factor of 65 percent.
[c] Assuming a heat value of 12,500 Btu/lb and a load factor of 65 percent.

SOURCE: Office of Technology Assessment.

be built simultaneously and construction workers will move from site to site. In addition, the construction workers for wood capacity probably would be needed for a shorter period of time due to the smaller plant size. Similarly, from three to seven times more plant personnel are required to operate wood-fired facilities than are needed for an equivalent capacity of larger coal-fired plants. Again, some operating and maintenance workers could be shared among several wood-fired plants located near each other. However, at sites where one large new wood-fired boiler replaces several old small oil-fired boilers, operating and maintenance jobs may decrease.[23]

Finally, employment associated with methanol plants is expected to be comparable to that in ethanol distilleries (discussed in the next section).

The manufacture of wood energy conversion equipment also will represent a number of employment opportunities. For example, the Wood Energy Institute lists 7 firms producing commercial wood boilers, 12 manufacturing residential boilers, and 73 companies making residential wood stoves. In addition, the Institute lists several hundred wholesale and retail suppliers of wood energy conversion equipment. While the current number of employees in these firms is unknown and future employment is difficult to predict, the opportunities —especially for small business employment — are substantial, and will expand as emerging conversion processes such as gasification and onfarm distillation become widely used,

Based on the distribution of the wood resource base and the location of existing wood energy activities, it seems likely that new employment will arise in rural areas, primarily in the South, North, and Pacific coast regions. Where these rural areas currently experience unemployment or underemployment, wood energy jobs will be welcomed. For example, because timber can be harvested almost year round and is harvested most intensively in the winter, wood energy may mitigate seasonal employment problems in the North.[24]

However, a major concern accompanies the increased employment related to wood energy —the high incidence of occupational injury and illness in wood production relative to fossil-fuel-related occupations. Table 7 shows that the rates of reported occupational injuries and illnesses per worker in forestry, logging, and total lumber and wood products are significantly higher than the national average for all private industries. The total incidence rates per worker in logging and in lumber and wood products are almost twice those for coal mining. In terms of output, the logging and wood products sector has 14 **times** more occupational injuries and illnesses per Quad of fuel produced than coal mining, and 28 times more than oil and gas extraction. However, recent experience with the more mechanized equipment used for whole-tree harvesting indicates that there may be a much lower injury rate for the production of energy chips than is associated with traditional logging, although the actual number of injuries could still increase.

Harvesting and using wood for residential heating also could pose safety hazards, Amateur wood harvesting can be associated with a variety of accidents including those related to improper use of saws and axes as well as falling trees. In addition, improperly installed or maintained wood stoves and fireplaces are responsible for as many as 6,700 explosions and home fires each year.[25]

These safety considerations raise a variety of issues. Unless safer logging techniques are developed and enforced, the widespread use of wood energy will increase occupational accident rates and the resulting disruption of personal and family life, as well as public expenditures for workmen's compensation insurance and benefits. These occupational risks could become an issue in labor-management relations in the woods as they have in the coal mines, and thus could increase the risk of

[23] Private communication with Charles Hewett, Dartmouth College, 1980.

[24] Ibid

[25] Private communication with US Fire Administration [ ),1 t,1 Center Based on a 1977 78 survey of fire departments 111 15 States

Table 7.—Occupational Injury and Illness Rates, 1976[a]

	1976 annual average employment (in thousands)	Total cases[b] per 100 full-time workers	Lost workday cases per 100 full-time workers	Total cases[b] per Quad produced	Lost workday cases per Quad produced	Average number of days lost per lost workday case
Private sector (all industries)[c]	64,690	9	4	—	—	17
Forestry	11	13	5	—	—	21
Logging	84	25	14	—	—	—
Total lumber and wood products[d].	677	22	10	28	12	17
Bituminous coal mining .	224	13	8	2	1	25
Oil and gas.	345	13	6	1	0.5	45

[a]These figures only include the occupational injuries and illnesses that are reported the numbers in some sectors are actually higher because of unreported accidents
[b]Includes fatalities
[c]Excludes farms with fewer than 11 employees
[d]Includes logging

SOURCE Bureau of Labor Statistics. *Char(book on Occupational Injuries and Illnesses in 7976,* Washington D C U S Department of Labor. report 535 (1978). and Office of Technology Assessment

Photo credit USDA, George *Robinson*

Wood harvesting can pose safety hazards

labor-related fuel supply interruptions. Similarly, in the absence of comprehensive safety standards and building codes, more frequent home accidents and fires will cause personal suffering and increase private insurance claims and rates for wood-burning homes.

Increased production and use of wood energy could have other impacts as well, including effects on local tax revenues and forestland prices and ownership patterns, Much of the wood available for energy is privately owned and is classified as noncommercial for local tax purposes. In many areas, producing timberland is taxed at a **lower rate** than nonproducing, and harvesting this land for energy would shift the tax classification and reduce local tax revenues. On the other hand, the construction of large conversion facilities (such as methanol plants or powerplants) will contribute substantial amounts to local revenues. Also, increased demand for wood energy could increase the price of forest land. Moreover, in the regions with the highest potential for stand improvement—the eastern half of the United States – existing wood lots presently tend to be highly dispersed and owned in small units. As prices rise, these woodlots or their timber rights might be bought or leased by the timber products industry or conversion facility operators, or by State or Federal agencies, to facilitate efficient management.

Alcohol Fuels

Introduction

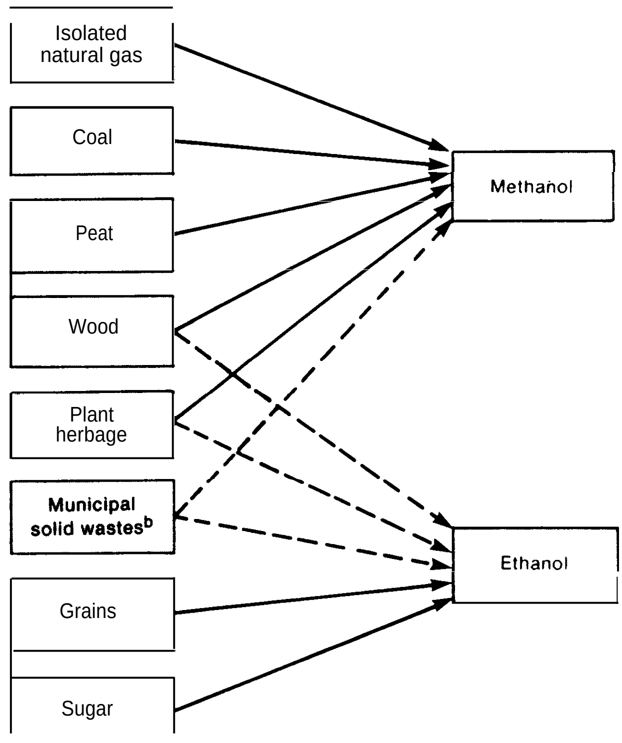
In early 1980, the United States consumed 600 million to 900 million gal/yr of gasohol, a mixture of gasoline and ethanol. (This corresponds to 60 million to 90 million gal/yr of ethanol.) Mixtures of methanol and gasoline may also be feasible or the alcohols could serve as standalone fuels for many uses, including transportation fuel in properly modified automobiles. With total U.S. consumption of gasoline running about 110 **billion** gal/yr, gasohol represents a small fraction of the current fuel Supply,

Nonetheless, gasohol and alcohol fuels have attracted considerable interest because the ethanol or methanol can be produced from domestic, renewable resources (figure 21), and the alcohol fuels have a wide range of applications (figure *22).* Alcohol fuels, in other words, are seen as one of many means for lessening the United States' dependence on imported oil (current imports are about **7 million** bbl/d or about 100 billion gal/yr).

OTA's analysis indicates that the potential for alcohol fuels from biomass is highly dependent on the feedstock used to produce the alcohol. Conservative estimates indicate that ethanol production from grains and sugar crops may be limited to 2 billion gal/yr, before competition for the feedstock and cropland increases food prices significantly.[26] At the 2-billion-gal/yr production level, ethanol could reduce U.S. demand for oil imports by 120,000 bbl/d, a cut of 1.5 percent from the present level, if it is used as an octane-boosting additive in gasoline and produced in distilleries not fueled by oil. Use of this amount of alcohol as a diesel fuel substitute (e.g., on farms) would displace only about 50,000 bbl/d of oil or less than 1 percent of oil imports.

Figures 23 and 24 show the geographical distribution of existing cropland and of land with

Figure 21 .—Likely Sources of Fuel Alcohols[a]



[a] In principle either alcohol can be made from all of the sources shown and many others as well (Methanol by means of carbon monoxide hydrogen synthesis and ethanol by means of ethylene oxide synthesis or hydrolysis fermentation) Where two lines are shown the solid line represents the route that probably will produce the less expensive fuel

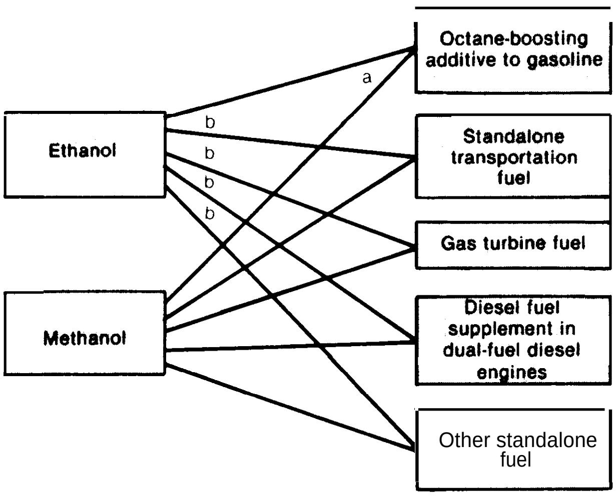
[b] Plastics in municipal solid waste may Interfere with methanol synthesis Consequently ethanol synthesis may prove 10 be the less expensive liquid fuel from this source

SOURCE Office of Technology Assessment

a high or medium potential for conversion to cropland. If grains and sugar crops are the principal ethanol feedstocks, then States with large cropland resources will gain the most in agricultural revenues. Benefits to these States may include greater gasohol availability but probably would not include preferential access to liquid fuel in general (except for on-farm distillation or if allocation decisions favor gasohol) because liquid motor fuels displaced by ethanol could become available elsewhere.

[26] See ch. 5, and R. L. Meekhof, W. E. Tyner, and F. D. Holland, "Agricultural Policy and Gasohol," Purdue University, May 1979.

Figure 22. —Uses of Alcohol Fuels



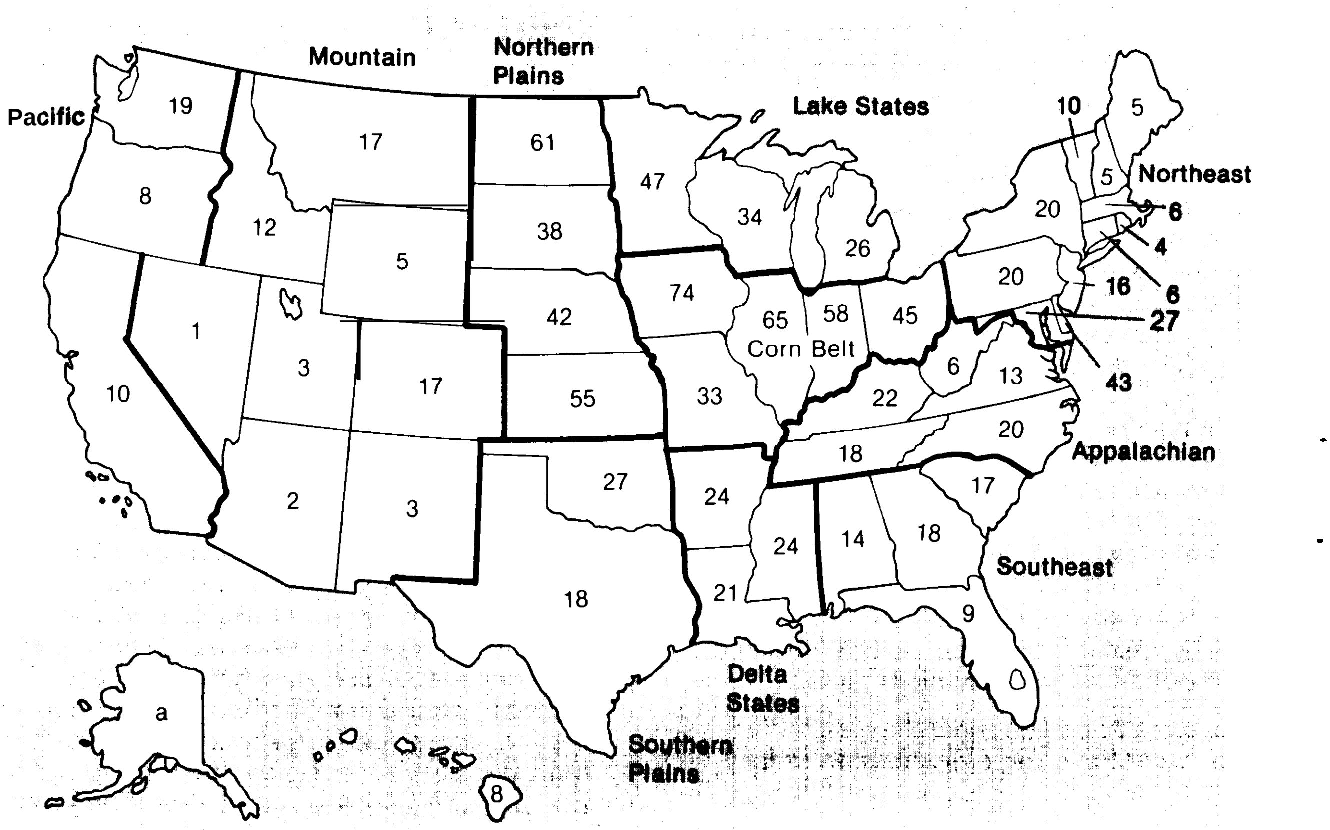
[a]May need other additives
[b]Probably not a preferred use if derived from grains and sugar crops

SOURCE Office of Technology Assessment

The greatest potential for alcohol fuels from biomass, however, comes from wood, grass and legume herbage, and crop residues (lignocellulose). Methanol can be produced from wood with existing technology although no facilities exist at present. Processes using grass and legume herbage and crop residues probably would be quite similar, although the use of these feedstocks must be demonstrated. By the mid- to late 1980's, processes for economically producing ethanol from these materials also may be available.

Although actual market penetration is difficult to predict, converting 4 Quads/yr of wood, grasses, and crop residues to methanol would yield about *30* billion gal/yr. Assuming that **7 billion** gal are used as octane-boosting additives to gasoline and that the remaining 23 billion gal are used as standalone fuel, then

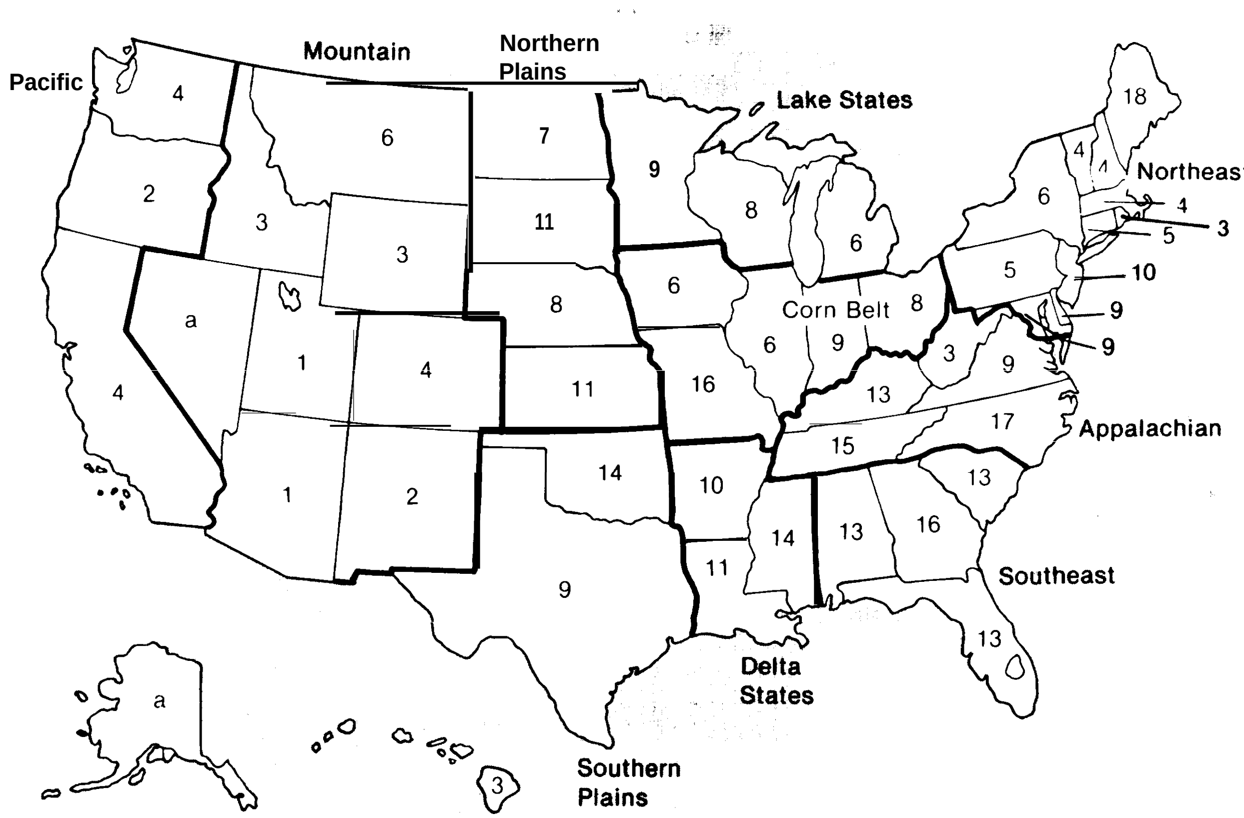
Figure 23.—Cropland as a Percentage of Total Land Area, by Farm Production Region



[a]Less than 0.5 percent.

SOURCE: Soil Conservation Service, U.S. Department of Agriculture.

Figure 24.—Potential Cropland With High or Medium Potential for Conversion, as a Percentage of Total Land Area



[a]Less than 1%

SOURCE: Soil Conservation Service, U.S. Department of Agriculture

this quantity of methanol would displace about 1 million bbl/d of oil, or about 12 percent of the current imports. A similar displacement of imported oil probably could be achieved by converting this type of biomass to fuel ethanol, although commercial processes for doing this are too poorly defined at present to make a satisfactory estimate.

There is also the possibility of producing other alcohols and related chemicals that are suitable as fuels. Although future developments could make these alternatives more attractive economically, ethanol currently appears to be superior in terms of commercial readiness, and methanol in terms of the quantities that could be produced in the 1980's.

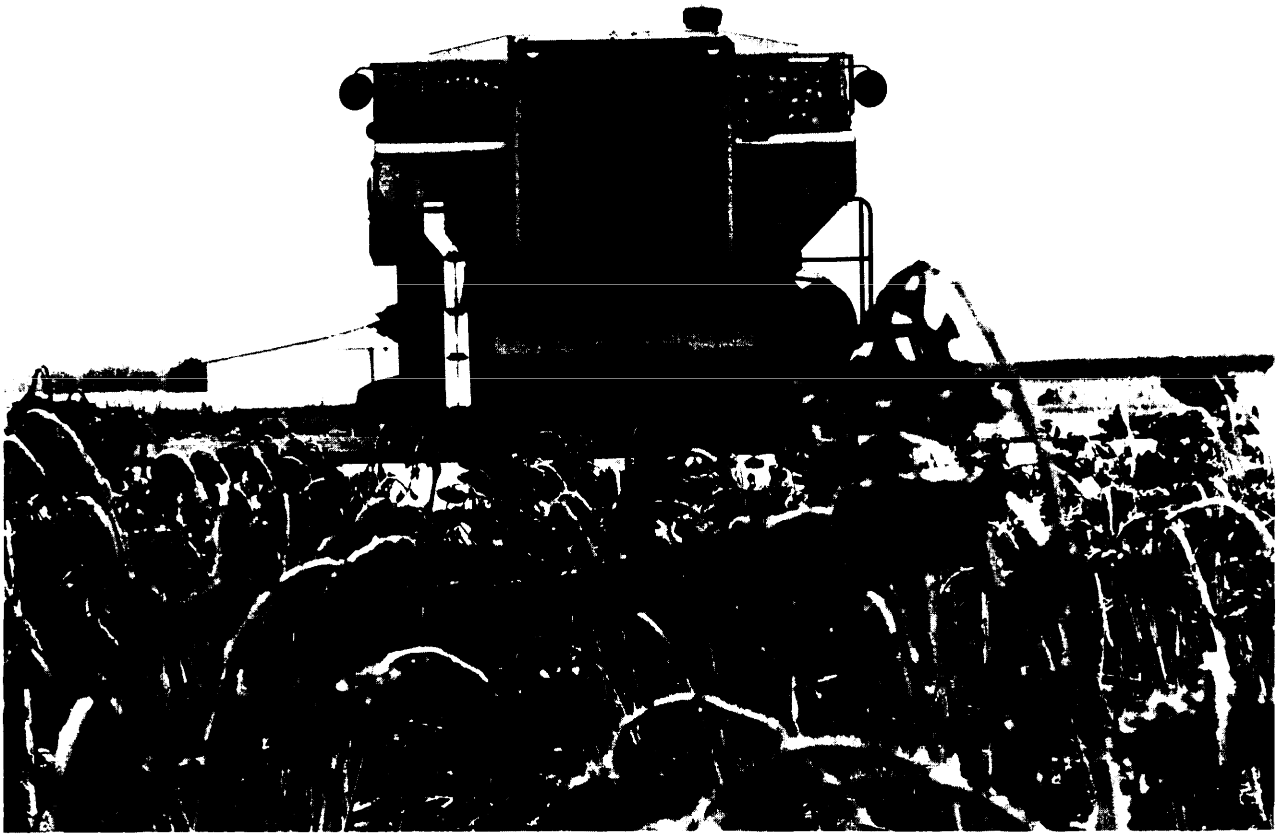


Photo credit USDA, Lowell Georgia

Although alcohol fuels from biomass have attracted the most attention, other sources of liquid fuels, such as sunflowers, may prove to be attractive for onfarm use

Technical Aspects

Gasohol is a blend of 90 percent unleaded gasoline and 10 percent ethanol (ethyl alcohol or grain alcohol). Although information is incomplete, it is probable that most cars in the existing automobile fleet can use gasohol with only minor changes in mileage and performance. An unknown number of cars, however, will stall or have poorer performance with gasohol due to a variety of causes. The longer term effects of gasohol on the existing fleet are largely unknown. * Nevertheless, because most new cars sold in the United States are warranted for gasohol use, these problems are likely to disappear as older cars in the fleet are replaced with new cars.

A 7 percent methanol (methyl alcohol or wood alcohol) blend is roughly equivalent to a 10 percent ethanol blend in terms of the fuel's leaning effect. * Due to the greater reactivity of methanol, however, it is likely that more cars will experience problems with methanol than with ethanol blends. Again the information is incomplete, but it has been estimated[27] that a minority of the existing fleet would be seriously affected[28] with 5 percent methanol

*See "Use of Alcohol Fuels" in vol. II

*The alcohol changes the effective air-to-fuel ratio so that there appears to be more air and less fuel; this is called "leaning."

[27]Private communication with R. K. Pefley, Santa Clara University, School of Engineering, Santa Clara, Calif.

[28]K. R. Stamper, "50,000 Mile Methanol/Gasoline Blend Fleet Study—A Progress Report," *Proceedings of Third Asilomar*, Calif., May 28-31, 1979.

blends. There is, however, no good way to judge the accuracy of this estimate, and, as with ethanol, the longer term effects are largely unknown.

The more serious problems with methanol blends appear to be at the oil refinery and in the distribution system. Although both ethanol and methanol blends can separate into two phases (layers) if exposed to water, the methanol blends are more sensitive to this problem and more stringent precautions must be taken to ensure that the methanol blends remain dry. Alternatively, cosolvents that decrease the water problem may be developed; one such cosolvent currently is being test marketed with methanol blends by Sun Oil Co.[29]

Another problem with methanol blends is their high vapor pressure, which increases evaporative emissions from most cars and increases the possibility of vapor lock. The composition of the gasoline can be adjusted to reduce the vapor pressure, but this reduces the volume of usable gasoline produced from a given amount of crude oil. Consequently, it may be preferable to construct new cars to accept blends with high vapor pressures, or to use cosolvents to reduce the vapor pressure. 30

In the 1980's, if new cars are built to tolerate alcohol-gasoline blends and appropriate fuel-handling techniques are developed and used, these problems should disappear gradually. If more cars are equipped with automatic feedback carburetor adjustment devices (as in the three-way catalyst cars in California), gasohol with an alcohol content of more than 10 percent may also become usable.

The addition of alcohol to gasoline raises the octane of the blend over that of gasoline. The exact increase depends on the widely varying composition of gasoline. Tests indicate that 10 percent ethanol will raise the octane of "average" gasoline by three to four octane numbers; a comparable increase results from methanol. The development in the 1980's of automobile engines that do not require high **octane fuels,** however, would eliminate any energy savings or economic advantage that this effect gives alcohol fuels when used in these engines. Nevertheless, it is likely that a substantial fraction of the automobile fleet will continue to need relatively high octane fuels well into the 1990's.

Automobiles also can run on pure alcohol. Indeed, cars specifically designed for alcohol will operate more efficiently than their gasoline-burning counterparts. The efficiency (miles per Btu) of an ethanol- or methanol-fueled engine can be 20 percent greater than most gasoline engines due to the high octane of these fuels, which allows a higher compression ratio in the engine, and to other modifications that improve efficiency. * The main hurdle in their development is overcoming starting difficulties in cold weather. With over 10 percent of the existing automobiles in captive fleets,[31] there is a considerable potential for using alcohols in this way before a nationwide commercial alcohol distribution network is in place.

Another use for alcohol fuels is in diesel engines built or modified for dual fuel use. The modifications are relatively simple, * * and a modified engine can use up to 30 to 40 percent alcohol while continuing to use straight diesel fuel when no alcohol is available. This option could be useful when establishing an alcohol distribution network, because users would not be tied to a supply of alcohol.

Alcohols can also be used as a substitute for light distillate oils and natural gas in gas turbines used for peakload electric generation. The modifications needed to use alcohols are relatively minor in most cases and there is a potential for displacing about 130,000 bbl/d of light distillate oil and about 100,000 bbl/d equivalent of natural gas.[32] Displacing all of the light distillate oil could increase gasoline supplies by about 130,000 bbl/d, or about 2 percent of current consumption.

[29] B C **Davis** and W H Douthut, "The Use of Alcohol Mixtures **as** Gasoline Additives, " Suntech, Inc , Marcus Hook, Pa , presented at 1980 NPRA annual meeting, March 1980

[30] Ibid

"See "Use of Alcohol Fuels" in vol II

[31] Transportation Energy Conservation *Databook* (*2d edition*, Oak Ridge National Laboratory, October 1977), ORNL-5493

** See "Use of Alcohol Fuels" in vol II.

[32] H R Adelman, R K Petley, et al , "End Use of Fluids From Biomass as Energy Resources in Both Transportation and Non-Transportation Sectors, " contractor report to OTA, January 1979.

Photo credit USDA, David F Warren

Diesel farm machinery can be modified for dual fuel use

The options for distributing and using the alcohols as standalone fuels require equipment modifications, but do not suffer from most of the problems with handling and storing the blends. On the other hand, using the alcohols' chemical properties as octane-boosting additives to gasoline enables many oil refineries to reduce their energy consumption by producing a lower octane gasoline. However, the actual energy savings and the complications vary considerably depending on the specifics of the refinery, the crude oil used, the distribution techniques, and the end use. For ethanol, the preferred use is probably as an octane-boosting additive to gasoline. But there is a need — particularly with respect to methanol — to study the refineries, the petroleum distribution system, and various end uses for the alcohols (including hydrocarbon synthesis) to determine the best strategies (both in terms of energy and cost) for expanding their use as oil substitutes.

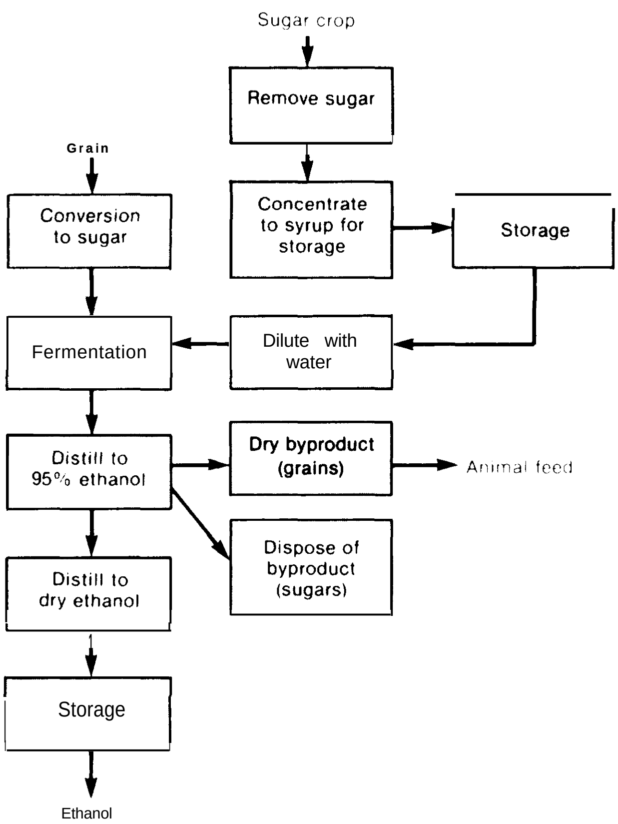
Ethanol

Ethanol can be produced from grains and sugar crops with commercially available technology. The grains generally provide a cheaper ethanol feedstock and the conversion is less expensive because they can be stored more easily than most sugar crops, which often must be reduced to a syrup prior to storage, Furthermore, grain distillation produces a byproduct that can be used as a partial substitute for protein meal in animal feeds.

As shown in figure 25, in making grain ethanol, the distiller produces a sugar solution from the feedstock, ferments the sugar to ethanol, and then separates the ethanol from the water through distillation. In distillation, the water-ethanol solution is boiled and the vapors pass through a column causing numerous evaporation-condensation cycles, each one of which further concentrates the ethanol up to 95 percent. Higher concentrations, with current technology, require further distillation with the addition of chemicals. The capacity of the typical commercial distillery ranges from 10 million to 50 million gal/yr of ethanol,

Energy is consumed in the production of ethanol both in growing the crop and distilling the ethanol (figure 26), As mentioned above, beyond the energy content of the ethanol, additional energy usually can be saved at the oil refinery by using ethanol as an octane booster in gasoline because it usually requires less energy to produce a lower octane gasoline.

Figure 25.—Synthesis of Ethanol From Grains and **Sugar Crops**



SOURCE: Office of Technology Assessment

It gasohol is to reduce U.S. dependence on o i l i reports, it is crucial that as little oil is consumed in the production of et ha no l from grain or sugar as possible. While not much can be done about oil and natural gas consumption in the growing of ethanol feedstocks, distilleries should be required to use fuels other than petroleum as a boiler fuel. Otherwise, the oil consumed at the distillery will eat up a significant fraction of the oil displaced by ethanol use, even with foreseeable improvements in the energy efficiency of distilleries. (If natural gas is used as a distillery fuel, then a significant part of the o i l displacement is achieved at the expense of increased natural gas consumption)

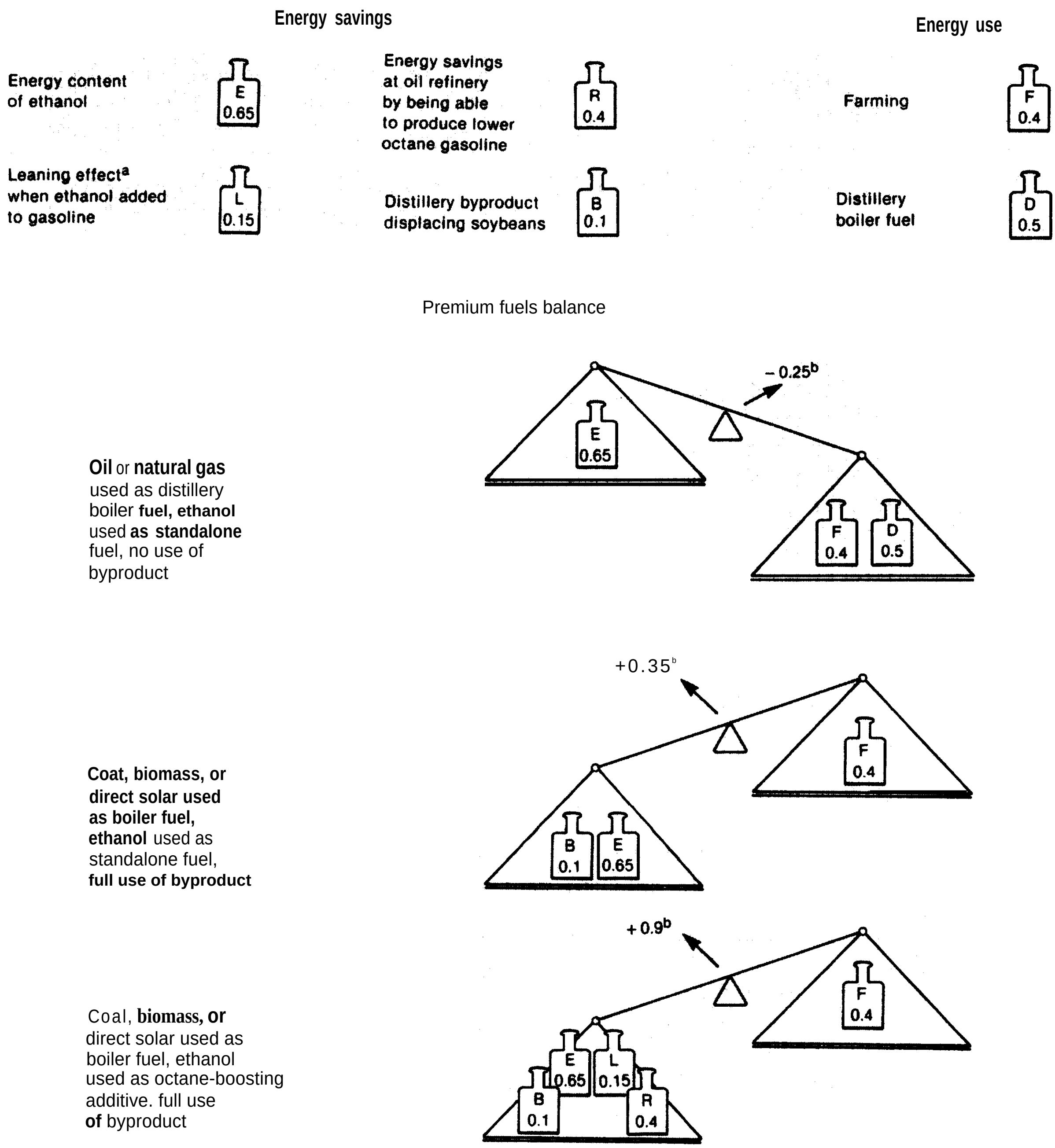
If used as an octane-boosting additive and distilled without use of premium fuels, each gallon of ethanol can displace up to about O *9* gal of gasoline. (This is a displacement of premium fuel only,) In contrast, if ethanol distilleries are fueled with oil and distributors do not take advantage of ethanol octane-boosting properties, * gasohol production actually could result in a net **increase** in oil demand. I f ethanol distilleries are fueled with coal or biomass, but the ethanol is consumed in engines in which it is only useful for its fuel value (e. g., diesel engines or engines not requiring a high-octane fuel), then each gallon of ethanol from corn would displace, on the average, only 0.3 to *0.5* gal of gasoline, depending on the engine used. The net displacement of premium fuels can be considerably *lower,* however, if more energy-intensive crops are used.

Because most onfarm uses of ethanol would be as diesel fuel substitutes, emphasizing alcohol production for onfarm use would greatly decrease the net oil displacement that could be achieved at any given level of ethanol production. Onfarm production of wet ethanol (5 to 10 percent water) from grains or sugarcane is relatively simple, but the processes need to be automated in order to minimize labor requirements. Onfarm production of dry alcohol cannot be accomplished economically with commercially available technology, although less expensive processes and equipment may be developed in the future. Consequently, ethanol would have to be dried at central facilities if it were to be used in gasohol. Numerous site-specific constraints would also limit the number of farms where wet ethanol production would be economic. There is, however, insufficient experience with onfarm ethanol production to establish truly reliable cost estimates. Nevertheless, farmers may wish to produce ethanol as an insurance against diesel fuel shortages and in the hopes that it will raise **grain prices. * ***

*Ethanol's octane boosting properties will be properly utilized it the ethanol is mixed with a reduced octane gasoline to form a "regular-grade" gasohol, or it the ethanol is added to regular unleaded gasoline to form a premium-grade fuel *that is then substituted for premium unleaded gasoline*. Because forecasts of future gasoline production indicate significant production levels for such premium fuels, it appears likely that the potential energy savings associated with ethanol's octane boost will be realized. To the extent that motorists may use premium-grade gasohol in place of unleaded regular gasoline, the "octane boost-related" energy savings will be lost, however.

**See "What Are the Problems and Benefits With Small-Scale Bioenergy Processes?" in ch. 3.

Figure 26.—Premium Fuels Balance for Ethanol
(all numbers are gallons of gasoline energy equivalent per gallon of ethanol)



[a]This effect results from alcohol s tendency to produce an air/fuel ratio that appears to have more air and less fuel, this Increases the thermal efficiency of most cars Cars with automatic carburetor adjustment would not show this effect
[b]Uncertainty of ± O 3

SOURCE: Office of Technology Assessment

Commercial processes might become available for producing ethanol from wood, grass, crop residues, and other lignocellulose materials at prices comparable to current grain processes by the mid- to late 1980's One process — the Emert process, formerly the Gulf Oil Chemicals process--might be commercial by 1981-85, but significant uncertainties remain concerning the ethanol costs from this process.

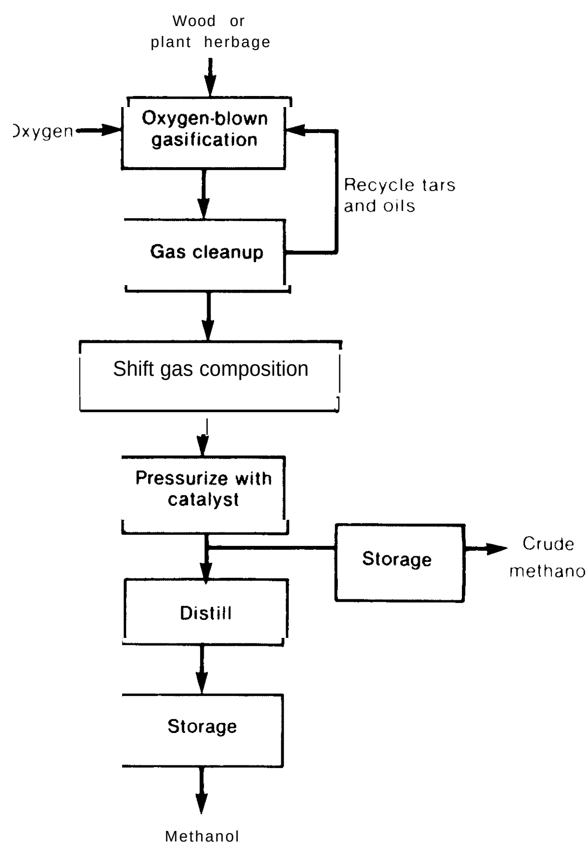
Methanol

Methanol originally was produced from wood, but only as a minor byproduct of charcoal production. Methanol, however, can be produced from wood with existing technology (construction time: **2 years) using oxygen-blown gasifiers (figure 27) although no plants exist at present** in the United States. Crop residues or grass and legume herbage also are feasible feedstocks, but oxygen-blown gasifiers capable of handling them must be demonstrated.

Methanol synthesis consists of gasifying the biomass to make a carbon monoxide-hydrogen mixture, The ratio of these two components is adjusted and the mixture cleaned and pressurized in the presence of a catalyst to produce methanol. Although relatively small methanol plants could be constructed, there is a significant economy of scale. Furthermore, plants with a capacity of less than about 3 million to 10 million gal/yr will require a different type of compressor than that used in large plants; this could increase the costs further. *

Methanol, like ethanol, can be blended with gasoline and used as an octane-boosting additive. Although methanol contains 25 percent less energy per gallon than ethanol and **50** percent less than gasoline, the net displacement of oil from producing and using a gallon of methanol from wood is as much as that for a gallon of ethanol because it takes less energy to grow, harvest, and transport trees from the forest than it does to produce grains or sugar crops. If the methanol is derived from crop residues or grasses, the net displacement per gallon of alcohol is slightly less than with wood due to the larger energy required to obtain the farmed feedstocks, but it still falls in the same range as for the various grains and sugar crops. As with ethanol, the displacement is maximized by using the methanol as an octane-boosting additive, but there are still some unresolved questions about the best strategies for expanding the use of methanol as a fuel. Unlike ethanol, however, there is very little danger that fuel methanol production could lead to an increase in oil consumption.

Figure 27. —Methanol Synthesis



SOURCE Office of Technology Assessment

*See "Thermochemical Conversion" in vol. II

Economics

The economics of fuel alcohol depend on the feedstock as well as the way the fuel is used. Grain and sugar feedstocks for ethanol production are considered below, while the methanol feedstocks, including wood, grass and legume herbage, and crop residues, are considered in the other fuel cycle sections. Aside from waste byproducts and some types of crop substitutions, the principal difference between these types of feedstocks is that grain and sugar production cannot be increased as much as wood and herbage production, because high-quality cropland suitable for grain and sugar crops is nearer to its productive limits (with existing technology) than is pastureland or forestland. Consequently, inflationary competition between fuel and other uses for the feedstocks is likely to occur at lower levels of alcohol production from grain and sugar crops than from wood and herbage. For wood, however, the truth of this statement will depend to some extent on the type of forest management that accompanies the increased wood energy harvests.

Ethanol

Ethanol costs vary according to the feedstock used (table 8) and the size of the distillery. Ethanol can be produced from corn ($2.50/bu) in a coal-fired 50-million-gal/yr distillery for $1.1 9/gal with 100-percent private equity financing, including a 13-percent return on investment, or for $0.96/gal with 100-percent debt financing. * The investment capital is about $68 million (early 1980 dollars) for a 50-million-gal/yr distillery. To the $0.96 to $1 .19/gal cost, delivery costs must be added –$0.10 to $0.30/gal for deliveries of up to 1,000 miles from the distillery. Currently, ethanol is transported in tank trucks, but as production volume grows other forms of transportation such as barge, rail tank cars, and possibly pipeline may come into use. Under favorable circumstances, these modes could reduce ethanol transportation costs to less than $0.10/gal.

Calculated simply on the basis of its energy content, ethanol costing $1 .20/gal is equivalent to gasoline selling at the refinery gate for $1 .78/gal or about $46/bbl crude oil. However, such a calculation fails to take into account ethanol's octane-boosting properties or its effect on engine efficiency. Although the cost varies depending on the gasoline and other specifics, OTA estimates that ethanol could be competitive, without subsidies, as an octane-boosting additive if the ethanol costs no more than 1,7 to 2.5 times the crude oil acquisition price. * *

*See "Fermentation" in vol. II.

**The average crude oil acquisition price was about $22/bbl in January 1980, but will probably increase to about $30/bbl by the end of 1980. For further details see "Use of Alcohol Fuels" in vol. II and box F.

Table 8.—Cost of Ethanol From Various Sources[a]

Feedstock	Price[b]	Net feedstock cost[c] ($/gal ethanol)	Ethanol cost ($/gal)	Yield[d] (gal of ethanol per acre)
Corn	$2.44/bu	$0.57	$0.95-1.18	220
Wheat.	$3.07 -4.04/bu[e]	0.73-1.08[e]	1.11-1.69	85
Grain sorghum.	$2.23/bu	0.49	0.87-1.10	130
Oats	$1.42/bu	0.59	0.97-1.20	75
Sweet sorghum	$15.00/ton[f]	0.79	1.25-1.63	380[e]
Sugarcane	$17.03/ton[g]	1.26	1.72-2.10	520

[a]The production costs have been updated from OTA's technical memorandum on Gasohol to reflect early 1980 costs
[b]Average of 1974.77 seasonal average prices
[c]The difference in feedstock costs might not hold over the longer term due to equilibration of prices through large-scale ethanol production
[d]Average of 1974.77 national average yields
[e]Range due to different prices for different types of wheat
[f]Assuming 20 fresh weight ton/acre yield, $300/acre production cost
[g]Excludes 1974 data due to the anomalously high sugar prices that year

SOURCE U S Department of Agriculture, *Agricultural Statistics*, 1978, and Office of Technology Assessment

Box E.–Two Ways to Calculate the Value of Ethanol

OTA presents here two methods to calculate the value of ethanol to a potential buyer. One method focuses on the ethanol's **energy value and the other on its current market value. Although the values calculated** in the two examples will change as better data **become available or as market conditions change, the methods should be valid independent of these changes.**

1. A **refinery is the potential buyer. Assume that ethanol's value is related only to its ability to deliver automobile mileage or to save energy at the refinery. –Although there is considerable uncertainty associated with the effects of ethanol on auto efficiency, available tests indicate that a gallon of ethanol will displace about 0.8 gal** ***of gasoline*** (i.e., gasohol mileage is 2 percent less than gasoline mileage). The refiner can also save some of the fuel needed to power the refinery— the energy equivalent of about 0.4 gal of gasoline for each gallon of ethanol — by taking advantage of ethanol's octane-boosting properties and producing a reduced octane gasoline to mix with it. (If the **refinery savings turns out to be significantly less than this estimate–as claimed by some sources—then the value of ethanol to a refinery will be lower than that** shown here. See box D and "Use of Alcohol Fuels" in vol. I I for a discussion of the uncertainties associated with this estimate). At the refinery gate, unleaded regular costs about 1.6 times the crude oil price. Assuming that the fuels saved by the octane boost, which are of lower value than gasoline, cost about the same as crude oil, the ethanol is valued at about

   gasoline saved x gas **price + refinery** fuels saved x fuel price
   =(0.8 x 1.6 + 0.4 Xl .0) x oil price
   = 1.7 times the crude oil acquisition price.

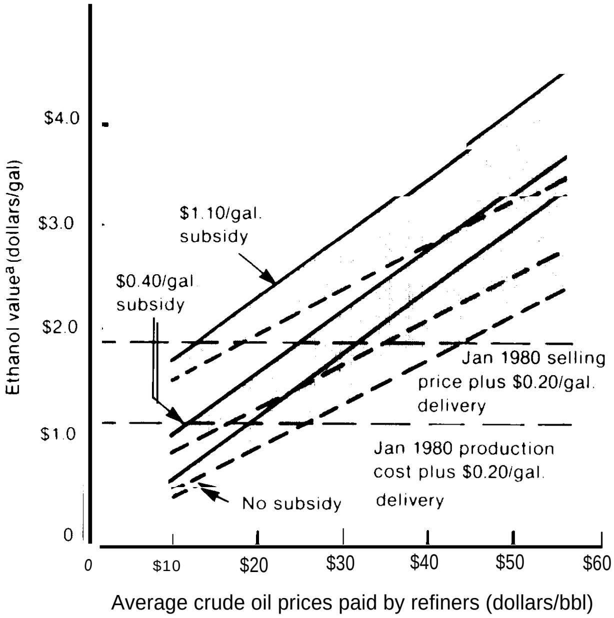
2. A **gas station is the potential buyer. Assume that the current markup the station obtains on gasohol will not change as the gasohol market matures.** –Gasoline retailers bought regular unleaded gasoline for about $0.70/gal in July 1979 **and sold gasohol** for a rough average of $0.03/gal more than regular unleaded. (The difference between this and the **retail price of gasoline** is due to taxes and service station markup, which total about $0.29/gal.) One-tenth gallon of ethanol displaces a tenth gallon –$0.70 worth–of gasoline and should also be credited with gasohol's $0.03 markup, for a total value of $0.100, or $1 .00/gal. This is 2.5 ***times the July*** 7979 ***average crude oil price*** of $0.40/gal.

These two estimates of ethanol's "value" must be interpreted carefully **because they are based on averages, whereas individual buyers will make decisions based** on the *actual values* of crude oil acquisition price, gasohol markup, and other parameters that determine ethanol's value to them.

OTA concludes from the above estimates that ***in the absence of subsidies, manufacturers should be able to find markets for their ethanol if they can price it*** at or below 1.7 to 2.5 times the ***average crude oil price.*** This range is approximate, and changing **price relations between** crude oil and gasoline as well as the demand for high octane **fuels,** can **change** the range.

The price at which ethanol can be sold competitively as an octane-boosting additive, which is called its **value,** is displayed in figure 28 as a function of the crude oil acquisition price at varying levels of subsidies.

Figure 28.—The Estimated Value[a] of Ethanol as an Octane-Boosting Additive to Gasoline for Various Crude Oil Prices and Subsidy Levels



[a] Value is defined as the price at which the ethanol becomes competitive as an octane-boosting additive to gasoline

SOURCE: Office of Technology Assessment

Ethanol made from $2.50/bu corn in a 50-million-gal/yr coal-fired distillery can be delivered to a service station for $1.15 to $1.50/gal, making it competitive for blending with gasoline, using only the Federal subsidy on gasohol equivalent to $0.40/gal of ethanol. At this price ethanol would be competitive* without subsidies when U.S. refineries pay an average crude oil price of $19 to $37/bbl or when the average retail price of unleaded gasoline is about $1.05 to $1.80/gal.** This calculation, however, ignores the cost of modifying automobiles that experience problems with gasohol (estimated to be from $20 to $180/car affected [33]).

A variety of factors that affect the costs and pricing policies of refiners and distributors can raise or lower the estimated value of ethanol considerably.* To a large extent, these pricing policies will determine whether ethanol is economically attractive as an octane-boosting additive.

Another very important economic consideration involved with gasohol is the competition between food and fuel.

Up to this point, the discussion of ethanol economics has assumed the price of ethanol feedstock that would prevail for incremental supplies in the short run. In the longer term, if billions of gallons are desired from starch and sugar crops, distillers must bid up the price of feedstocks as an incentive to make additional feedstocks available. The three principal sources of the additional ethanol feedstocks are: 1) food and feed exports, 2) crop substitutions (e. g., growing corn rather than soybeans) with reformulation of livestock rations and possibly of human diets, and 3) expansion of the quantity of cropland under production. All these effects would occur simultaneously.

The first source represents a direct competition between domestic consumption and exports. Depending on harvests abroad and political decisions to embargo exports, the domestic price changes can vary considerably from year to year. Also, depending on how foreign demand changes with the prices of farm commodities (the elasticity of foreign demand), there may be an increase or a decrease in revenues from food and feed exports as grain prices increase.

Certain types of crop switching also can lead to increases in ethanol feedstocks (figure 29). One likely substitution is corn for soybeans; by using the byproduct of corn distillation to reduce demand for soybean meal, additional

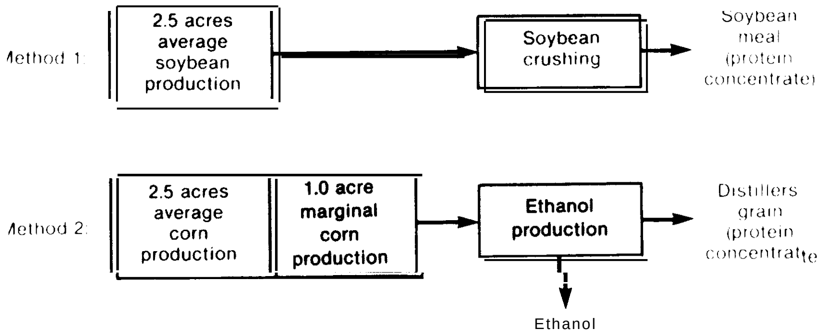
* Note that individual buyers will make decisions based on *actual* rather than *average* costs and benefits of ethanol. Thus, calling ethanol "competitive" here means only that profitable markets will exist. It does *not* mean that all possible buyers will actually want to buy ethanol, or that *all* producers will be able to market their product at a profit.

** Assuming gasoline price relationships, as follows: Refinery gate price equal to 1.6 times crude oil prices plus delivery and retail markups and taxes totaling $0.30 to $0.40/gal.

[33] J. A. Bolt, D. E. Cole, and D. J. Patterson, Engine Modification for Use of Methanol and Methanol Gasoline Blends, Department of Energy Highway Vehicle Systems Contractors Coordinating Meeting, May 12, 1978.

* See "Use of Alcohol Fuels" in vol. II.

Figure 29.—Crop Switching: Two Methods to Produce Equivalent Amounts of Animal Feed Protein Concentrate



Methods 1 and 2 provide equivalent amounts of animal feed protein concentrate

SOURCE Office of Technology Assessment

corn can be produced on some of the land that would have been in soybean product ion.* However, the amount of substitution is limited by the fact that the distillery byproduct is not a perfect substitute for soybeans.

Cattle also could be fed more forage and less corn, which would free corn for ethanol production, but would reduce the weight gain per animal per day and thereby reduce total beef production. Similarly, a reduction in the demand for grain-fed animal meat would provide additional ethanol feedstocks.

Cultivation on set-aside and diverted acreage often is cited as a possible source of ethanol feedstocks. In 1978 there were 18.2 million acres in these categories and the 1979 total was about 11.2 mill ion acres. The quantity of set-aside and diverted acreage, however, will fluctuate greatly from year to year. There is no assurance that this land will be available for energy production in the future.

OTA estimates that an additional 30 million to 70 million acres of potential cropland could be brought into crop production by the mid-1980's, over and above the land required for food, feed, or fiber production (figure 30). In the 1990's, however, the situation may become more precarious due to the expected increase in demand for food attributable to a larger U.S. population and increased export demand for U.S. food production. By 1990, the cropland available for energy biomass production could range from 9 million to 69 million acres and by 2000, it could be anywhere from zero to

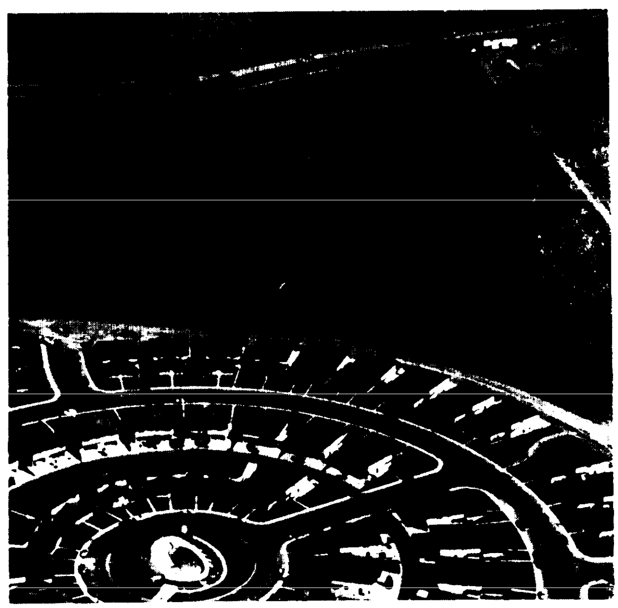
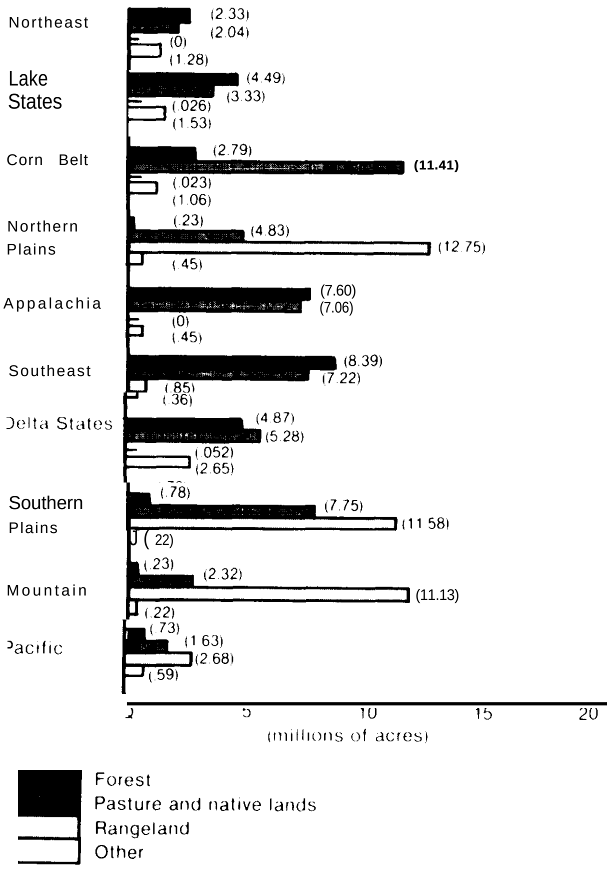


Photo credit USDA, J Clark

The conversion of cropland to urban and other nonagricultural uses will reduce the amount of cropland available for energy production

*See "What Is the Potential of Biomass for Displacing Conventional Fuels?" in ch. 3

Figure 30. —Present Use of Land With High and Medium Potential for Conversion to Cropland by Farm Production Region



SOURCE: 1977 National Erosion Inventory Preliminary Estimates, Soil Conservation Service, U.S. Department of Agriculture, April 1979.

65 million acres.[34] (The uncertainty in the availability of cropland for energy production corresponds to less than plus or minus 10 percent of the cropland needs in 2000. Consequently, it is unlikely that more accurate projections can be made 20 years into the future.)

With this flexibility in the sources of ethanol feedstocks, production will be limited primarily by the rate at which distilleries can be built in the next 3 to 5 years. By the 1990's production conceivably could reach a level of 7 billion to 10 billion gal/yr of ethanol from grains, but expanding the production level beyond 1 billion to 2 billion gal/yr could, according to conservative economic calculations, put ethanol into increasing competition with other uses for the farm commodities, [35] In the mid- to long-term, this competition could become severe. To maintain or expand an ethanol fuel **industry, distilleries might have to turn to cellulosic materials for their feedstock. Constraints here, however, may be the availability of capital** for the large investments that are likely to be needed to convert distilleries to cellulosic processes, and possibly the added cost of these conversion processes. Furthermore, the added complexity and equipment cost for these processes are likely to make them substantially less suited to onfarm or small-scale facilities. No definitive judgment can be made, however, until future cellulose-to-ethanol processes are better defined.

At this early stage in the development of the ethanol fuel industry, the cost of the feedstock is determined directly by the demand for food. Greatly expanded gasohol demand that requires substantially more than 2 billion gal/yr of grain-based ethanol could very well reverse this relationship, however, so that grain prices could become dependent on the demand for ethanol. The extent to which this will occur depends critically on how much cropland can be brought into production in response to rising food prices, the amount of crop switching that is practical, how easily grain can be bid away from export markets, changes in eating habits (e.g., less grain-fed meat) and, eventually, the cost of producing ethanol from cellulosic feedstocks, These and other uncertainties, such as weather, crop yields, and long-term changes in demand for food exports, make it impossible to predict the full impact of large-scale ethanol production on food prices or the exact production level at which food-fuel competition will start to become severe. But rough estimates based on the expansion of cropland in the early to mid-1970's (due to the increased demand for U.S. food exports) indicate that domestic food consumers could pay $3 to $4 per year in higher food prices for each additional

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[34] O. C. Doering, "Cropland Availability for Biomass Production," contractor report to OTA, August 1979.

[35] R. I. Meekhof, W. E. Tyner, F. D. Holland, op. cit.; and also see ch. 5.

Photo credit: USDA

Weather and other uncertainties can affect crop yields

gallon per year of ethanol* produced above the level at which food-fuel competition becomes severe, if feed price rises are used to bring more cropland into production and it distillery byproducts are utilized poorly. Nevertheless, numerous other factors such as a rise in the international value of the dollar due to decreased oil imports, which lowers the cost for all U.S. imports, could decrease these indirect costs of ethanol production.

No truly satisfactory estimates can be derived, but the increased food costs caused by the competition between food and fuel production could be enormous compared to the quantity of ethanol produced, and caution should be exercised when expanding ethanol production from grains and sugars beyond the 2-billion-gal/yr level.

Some controversy exists over whether the higher food costs should be characterized as an indirect cost of ethanol production. This point— that indirect costs for food consumers should be charged to fuel ethanol — is clearest when there is a Government subsidy such as the present tax credit for gasohol. This tax credit not only gives distilleries, and ultimately fuel users, an advantage, but it also forces food consumers to pay higher prices than would be paid under normal market forces. Without the subsidy, the price paid ideally would equal the cost of products for al l purchasers and, from a market viewpoint, greater economic value would be obtained from the same agricultural resources.

Even without Government fuel subsidies, serious questions remain about indirect costs to food consumers. If petroleum prices continue to spiral, expansion of ethanol production may cause unacceptable inefficiencies and inequities due to inelastic supply and demand for food. In other words, grain and sugar producers may have difficulty supplying both food and fuel needs, which are both relatively inflexible, so the net result would be that both food and feedstock prices would rise to extremely high levels to achieve a market balance.

Beyond the increase in food prices, increased demand for farm commodities also will tend to increase farmland prices and the year to year fluctuations in commodity prices. The former results from the increased demand for cropland and is necessary to expand the amount of cropland in production. The latter occurs because demand and supply for farm commodities may be relatively inelastic at large ethanol production levels and because the increased production occurs on lands where productivity is more sensitive to weather variations. Unless policies are instituted to increase the stabilization of farm commodity prices (e. g., by larger buffer stocks), the combination of higher farmland prices and increased commodity price fluctuations would put farmers who rent land or who have recent-

*Between 1970-71 and 1976-77, farm commodity prices received by farmers rose 12 5 percent (corrected for inflation) and the land used for production expanded by 39 million acres. Assuming 1) this response in the future, 2) that the farmers' share of retail food prices remains constant, 3) that the average yield on the new cropland is 65 bu of corn/acre, and 4) all of this corn is converted to ethanol, then the average increase in civilian food costs would be $3 25/gal of ethanol produced. A 12-percent increase in domestic civilian food costs is $21 5 billion. Thirty-nine million acres with 65 bu/acre could produce corn for 6 6 billion gal of ethanol. Data are from the U.S. Department of Agriculture, *Agricultural Statistics*, 1978 ly bought land in a more precarious situation economically. Furthermore, the need for larger buffer stocks and the higher cost of farm commodities also could increase Government expenditures needed to maintain the buffer stocks. On the other hand, farmland owners could reap a windfall gain from the increase in farmland prices. The net result would be an income transfer from food consumers and taxpayers to farmland owners and an increase in farming costs due to the higher land costs, the lower productivity of the new cropland, and the higher risk of farming it.

Although ethanol production can lead to greater fluctuations in the price and total supply of farm commodities, it also can provide a buffer against extreme deprivation. Because grain production would exceed the food and feed demand, distillery feedstocks could be diverted to food use if severe crop failures occurred at home or abroad. However, this would decrease fuel supplies and place a hardship on distillers and fuel users.

The production of fuel ethanol can influence a complex and interconnected set of markets. The exact impacts and market responses are difficult to quantify and compare. Decreases in U.S. dependence on imported oil also would decrease the vulnerability of the United States to political instabilities in oil-producing countries. However, decreases in grain exports could more than offset reduced expenditures for foreign oil. The impacts of increased food prices vary from reduction in domestic meat consumption to a greater risk of malnutrition at home and abroad, of windfall gains for farmland owners, of increased economic vulnerability of farmers who rent or have recently purchased land, and of retaliatory internat ional responses to reduced grain exports.

Methanol

As mentioned above, the economics of obtaining the methanol feedstocks — wood, grass, crop residues, and other dry plant material — are considered in the descriptions of the other fuel cycles. The production and end use are discussed below.

With methanol feedstock costs ranging from $20 to $60/dry ton, OTA estimates that methanol from biomass can be produced for $0.65 to $1.30/gal; and the investment would be roughly $100 million (early 1980 dollars) for a 50-million-gal/yr plant, or somewhat more than a 50-million-gal/yr ethanol distillery using grain feedstocks. For an average feedstock cost of $30/dry ton of wood, methanol can be produced for $0.75 to $1 .10/gal, depending on the financing of the distillery. About $0.10 to $0.30/gal should be added to this for delivery of the methanol.

Based solely on its energy content, methanol costing $0.90/gal at the plant is roughly equivalent to gasoline selling at the refinery gate for $1.77 or $45/bbl of crude oil. Like ethanol, however, methanol's octane-boosting properties increase the price at which it can be competitive as an additive to gasoline, which OTA calls its value. In a manner completely analogous to that used to calculate ethanol's value (see box E), methanol is estimated to have a value of 1.5 to 2.3 times the average crude oil prices paid by refiners, depending on whether it is blended at the refinery or at the gasoline station. (The upper value of 2.3 times the average crude oil price is particularly uncertain, because there is little marketing experience to judge the price consumers are willing to pay for methanol-gasoline blends, or the cost of cosolvents that ultimately may be used.)

Assuming the above range of values for the alcohol, methanol costing $0.95 to $1.40/gal (delivered) would be competitive as an octane-boosting additive to gasoline when average crude oil prices are $18 to $29/bbl, or when unleaded gasoline costs about $1.00 to $1 .90/gal.* This calculation, however, does not include the costs associated with additives or with changes in the refinery, automobile, or the fuel-handling system that may be necessary. It therefore represents a lower limit for the oil and gasoline costs at which methanol would be competitive. Although these added costs may be relatively small, an adequate

*Assuming gasoline price relationships as follows: Refinery gate price equal to 1.64 times crude oil prices plus delivery and retail markups and taxes totaling $0.30 to $0.40/gal.

evaluation of the factors is not currently available and is beyond the capability of this assessment.

General Aspects of Alcohol Fuels

Despite fluctuations in the supply of biomass feedstocks for producing alcohols, these fuels probably are a more reliable fuel source than imported oil, the supply of which is subject to the political whims of oil-exporting nations. This factor— reliability of supply—does not readily translate into dollars and cents, but it does enhance the value of the alcohols. In other words, the costs of oil supply disruptions can be considerable although they are extremely difficult to quantify.

Ethanol from grains and sugar crops shares an advantage with existing energy conservation technologies in that it uses current technology and thus may be an important energy alternative during the 1980's — before possibly less expensive, domestic synfuels and newer or improved conservation technologies become available (see table 9 for the estimated costs of various alternative liquid fuels). Methanol from wood probably shares this advantage, but plants must be constructed and operated before this is shown to be the case.

Ethanol and methanol, as standalone fuels, are unlikely to be competitive with methanol from coal, but they may be comparable in cost (per Btu) to the more expensive synfuels. However, future costs and supplies of the fossil-based synfuels are uncertain. The future costs of grains and sugar crops are also highly uncertain, as are the future costs of the cellulose-to-ethanol processes currently under development. Furthermore, the lack of a reliable supply infrastructure for fuelwood, grasses, and other lignocellulose materials introduces uncertainties into methanol production. These uncertainties in the future costs of ethanol, the lack of a feedstock supply infrastructure for methanol, and the uncertainty in the future demand for biomass alcohols may discourage private investment in alcohol synthesis facilities.

Some concern always will exist about introducing new transportation fuels that require

Table 9.— Estimated Costs in 1979 Dollars of Alternative Liquid Fuels[a]

Fuel source	Raw liquid $/million Btu	Refined motor fuel[b] $/million Btu	Refined motor fuel[b] $/gal	1990 potential (000 bbl/d)
Fuels requiring no automobile modification "				
Imported crude	$5.10'	$9.37	$1.17	4,500-8,500
Enhanced oil recovery.	3.00-7.00	5.50-12.90	0.69-1.61	300-1,500
Oil shale	5.90-7.30	12.50- 16.20[d]	1.56-2.03	30-300
Syncrude from coal.	5.10-8.50	10.90- 17.80[e]	1.37-2.23	50-500
Fuels requiring automobile modifications if used as standalone fuels				
Methanol from coal.	—	5.50-8.80	0.35-0.56	50- 500[f]
Methanol from biomass	—	10.20-20.909	0.65-1.309	50-500
Ethanol from biomass.	—	10.70-17.80	0.90-1.50	50-200

[a]Cost estimates for synfuels may be low because commercial.scale plants have not been built The values given encompass currently accepted best estimates

[b]In order t. compare refined liquids (e g methanol and ethanol) with unrefined liquids (e g crude 011 011, shale 011 and syncrude), the following methodology IS used Where necessary (shale 011 and syncrude), upgrading costs are added to the raw liquid costs The cost per gallon of refined liquids IS then assumed to be 1.64 times the cost per gallon of the upgraded raw liquid, which IS the current ratio of the cost of refinery gate regular unleaded gasoline and the average crude 011 acquisition cost

[c]$30/bbl

[d]Raw liquid cost of $35 to $43/bbl PIUS $500 to $9 00/bbl for upgrading

[e]Raw liquidcost of $30 to $50/bbl plu S $5.00 to $7 00/bbl for upgrading

[f]This is not additive to the potential of sync rude from coal

[g]This Price spread depends to a large extent on the range Of wood feedstock costs

SOURCES Off Ice of Technology Assessment; K A Rogers and R F Hill, *Coal Conversion Comparison*, prepared for U S Department of Energy under contract No EF-77-C-01 .2468 *Coal Liquids and Shale Oil as Transportation Fuels* a discussion paper of the Automotive Transportation Center. Purdue University, West Lafayette, Ind July 6 1979, and E E Bailey, "Methanol From Coal. An Adapt Ion From the Past. " *Energy,* PP 19-20. Fall 1979; Off Ice of Technology Assessment *An Assessment of Oil Shale Technologies* June 1980 modified handling techniques and can cause difficulties in some cars. Until the procedures are fully established, mistakes can cost a company some of its customers as well as added time and effort. Consumers also are confronted with inconveniences and costs they did not anticipate. The question surrounding the use of alcohol fuels is not whether the problems can be solved, but rather how to solve them in a way that minimizes the disruptions and costs.

Environmental Effects

Although attention has focused on the air quality effects of using alcohol blends in automobiles, each stage of the alcohol fuel cycle has significant environmental effects. The growing and harvesting of alcohol feedstocks probably will result in the most serious effects, although these effects will vary substantially in kind and intensity depending on the choice of feed stocks.

Obtaining the Feedstock

If grains and sugar crops are the primary feedstocks, production of ethanol in greater quantities than can be supplied by surplus crops and food wastes (a few hundred million gallons per year) may involve additional crop production through more intensive cultivation of present cropland and the development of potential cropland currently in forest, range, or pasture. A commitment to produce enough ethanol from these crops for a 10-percent blend in all automotive fuel could require putting as many as 30 million to 70 million acres into intensive crop production. The acreage could be significantly lower, however, if extensive crop switching is demonstrated to be a valid alternative to increasing acreage in product ion.*

Soil erosion and its subsequent impact on land and water quality will be a major consequence of an expansion of intensive agricultural production. Agriculture currently is the primary cause of soil erosion **in the United States** — at least a billion tons of soil from American farms wash into the Nation's surface waters each year.[36] The eroded soil causes turbidity, fills reservoirs and lakes, clogs irrigation canals, and damages aquatic habitats. In addition, the soil transports other pollutants including phosphorus, pesticides, and bacteria. Although the extent of the damage to aquatic ecosystems is unknown, yearly **material** damage from sedimentation has been estimated at over $1 billion.

Sustained soil loss also can damage land productivity, although it often takes a long time to do so. For example, a net loss of 10 ton/acre-yr leads to a loss of only an inch of topsoil in 15 years— and the loss in productive potential during this time may not be large on some lands because of their depth of topsoil or the nature of their subsoil. Even a significant loss may go unnoticed, because it may be masked in the short term by productivity increases resulting from improvements in other farming practices or more intensive use of agricultural chemicals. This lack of visibility may be one of the reasons why much of U.S. intensively managed cropland currently is eroding at rates in excess of Soil Conservation Service (SCS) guidelines. For example, sheet and rill erosion alone on intensively managed croplands averages 6.3 ton/acre-yr nationally and 7.3 ton/acre-yr in the Corn Belt, * while SCS guidelines call for rates below 5 ton/acre-yr (and less on more vulnerable lands). Indefinite continuation of this loss rate will eventually cause a decline in U.S. farmland productivity.

New intensive crop production for ethanol is likely to have more severe erosion problems-– per acre – than those described above for food and feed production (table 10). The lands most

*See "What Is the Potential of Biomass for Displacing Conventional Fuels" in ch. 3

[36] This is a conservative estimate. Many sources estimate between 2 billion and 3 billion tons, e.g., see *Environmental Implications of Trends in Agriculture and Silviculture, Volume I, Trend Identification and Evaluation* (Washington, D.C.: Environmental Protection Agency, October 1977), EPA-600/3-77-121.

' *Draft Impact Analysis Statement Rural Clean Water Program* (Washington, D.C.: U.S. Department of Agriculture, Soil Conservation Service, June 1978)

*Based on computer runs conducted for OTA by the Soil Conservation Service, from the 1977 *National Erosion Inventory*.

Photo credit USDA —Soil Conservation District

Agricultural operations can cause significant soil erosion problems

Table 10.—Erosivity of Cropland

Soil capability class[a]	Acreage now in intensive product ion, 10' acres (%)	Current erosion rates in these capability classes, b ton/acre-yr	Acreage that could be added,[c] 10^6 acres (O/.)
I	28 (9)	3.2	6 (3)
II	151 (50)	4.3	69 (38)
III	94 (31)	6.9	74 (40)
Iv	27 (9)	11.5	34 (19)

[a]A measure of the constraints on crop production (1) means excellent capability and few restrictions. while (IV) 'cans severe limitations on crop choice with special practices required
[b]Water-caused erosion only during Intensive production
[c]Present cropland not now in Intensive use plus land with high and medium potential for switching; this is likely to be an upper bound

SOURCE 1977 National Erosion Inventory

likely to be shifted to ethanol production appear to be about 20 percent more erosive than land that is presently in intensive crop production.* Also, if this land is less productive (as it is expected to be) than existing cropland in intensive production, then erosion rates per unit of production will go still higher.

A large expansion in intensively managed cropland will have important effects in addition to soil erosion. For example, pesticide use — currently about 1 billion lb/yr in the United States [38]— will probably expand somewhat proportionally to the expansion in crop acreage. Increased application of chemical fertilizers will also result. The runoff and leaching of nutrients to surface and ground waters will cause premature aging of streams and damage to aquatic ecosystems.

The increase in cropland will also lead to a transformation of unmanaged or lightly managed ecosystems, such as forests, into intensively managed systems. A large-scale national gasohol program would increase pressure to clear as many as 10 million to 30 million acres of unmanaged or lightly managed woodland.

All of the impacts associated with increased crop production are functions not only of the type of crops grown but also of land capability, production practices, improvements made to the land, and other factors. There is enough freedom of choice in the system to significantly reduce the environmental impacts of a major gasohol program. Aside from choosing the land to be cultivated as well as the crop and tilling procedure, farmers may reduce impacts by using a variety of environmental protection measures such as integrated pest management procedures, soil analysis to minimize fertilizer applications, and the development of disease-resistant crops. The Environmental Protection Agency (EPA) (through its section 208 areawide planning process to control nonpoint sources of pollution) and the Department of Agriculture (through SCS programs) have made only limited progress, however, in shifting farming practices toward less water polluting and more soil-conserving methods. * Also, there is considerable controversy surrounding the net environmental effects and the potential impacts on crop yields of some of the measures advocated as environmentally beneficial.

In light of farmer resistance to controls, the apparent low priority assigned most agricultural environmental problems by E PA, and the possibility that certain environmental measures may replace one adverse effect with another— for example, minimum tillage reduces soil erosion but increases herbicide use--OTA concludes that the environmental effects of converting tens of millions of acres to intensive grain and sugar crop production will be at least as severe as those found on existing cropland and probably worse where marginal land has been converted.

If alternative alcohol feedstock sources such as wood, crop residues, and grasses become primary ethanol feedstocks —or if methanol from these same feedstocks becomes an important fuel or fuel component—then the environmental effects will be markedly different from those discussed above (these effects are discussed in detail in the other fuel cycle sections). Because perennials provide more soil erosion protection than annuals, and close-grown crops more than row crops, intensified production of **grasses** (which are perennial, close-grown crops) will have few of the erosion problems associated with increased production of corn and other sugar and starch ethanol feedstocks. As much as 1 Quad/yr of **crop residues** may be harvested without exceeding SCS erosion guidelines, although strong pressures may have to be exerted to prevent excessive removals in some instances, and some questions have been raised concerning negative effects on long-term soil productivity (although OTA has not been able to identify convincing evidence of any adverse effect; see "Crop Residues"). Still larger quantities of

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*Based on computer runs conducted for OTA by the Soil Conservation Service, from the *1977 National Erosion Inventory*.

[38]*Draft Impact Analysis Statement Rural Clean Water Program*, op. cit.

[39]Based on data in "Tables of Potential Cropland," *1977 National Erosion Inventory — Preliminary Estimates* (Washington, D.C.: U.S. Department of Agriculture, Soil Conservation Service, April 1979).

*See "Environmental Impacts—Generic Concerns" at the beginning of this chapter.

wood are available from harvesting logging residues and intensifying forest management practices, the short-term effects of which potentially can be quite mild if properly controlled (but current regulatory and economic incentives for control may not be adequate, and questions have been raised about possible long-term degradation of forest soils; see "Wood Fuel Cycle"). Also, large-scale alcohol production based on crop residues and grasses may be accomplished without replacing other ecosystems, and the wood production may alter the character of much of the forest but can be accomplished without reducing the acreage of forested land.

Ethanol Production

Much of the energy required to run an ethanol plant is generated onsite in conventional boilers. Thus, a comparison to electric power generation is useful in getting a sense of the air pollution potential of the large-scale deployment of new ethanol-manufacturing capacity. New energy-efficient plants producing ethanol from grains or sugar crops probably will require at least *50,000* Btu/gal of ethanol produced to provide electricity and to power the distilling, drying, and other operations. * A 50-million-gal/yr distillery will consume slightly more fuel than a 30-MW powerplant. * * A 10-billion-gal/yr ethanol industry will consume about the same amount of fuel as a 6,000- to 7,000-MW electric power output.

The degree of air pollution control and subsequent emissions from new ethanol plants are not fully predictable, because New Source Performance Standards have not been formulated for industrial combustion facilities. The most likely fuels for these plants will be coal or biomass (crop residues, wood, etc.). The major source of any air pollution problems probably will be their particulate emissions. Coal and biomass combustion sources of the size required for distilleries, especially distilleries built to serve small local markets, will have to be carefully designed and operated to avoid high emission levels of unburned particulate hydrocarbons, including POM. The use of high-sulfur coal as a fuel —quite likely in parts of the Midwest–also could lead to high local concentrations of SO_2.

Water effluents from ethanol plants will require careful controls. The untreated effluent from the initial distillation step in ethanol production —called "still age"- is very high in biological and chemical oxygen demand and must be kept out of surface waters. The stillage from corn and other grains is a valuable feed byproduct and it will be recovered, thereby avoiding a potential water pollution problem. The stillage from some other ethanol crops is less valuable, however, and may have to be strictly regulated to avoid damage to aquatic ecosystems. Control techniques are available for the required treatment, although controls for still ages from some crop materials may require further development.

If fermentation and distillation technologies are available in a wide range of sizes, small-scale, onfarm alcohol production may become popular. The scale of such operations might simplify water effluent control by allowing the land disposal of wastes. On the other hand, environmental control may in some cases be more expensive because of the loss of scale advantages. In addition, as noted above, the smaller combustion sources are more likely to produce high emissions of unburned particulate hydrocarbons. Finally, the current technology for the last distillation step in producing anhydrous (dry) alcohol uses chemicals such as cyclohexane and ether that could pose severe occupational hazards at inadequately operated or maintained distilleries. Although safer dehydrating technologies may be developed, special care must be exercised in the meantime to ensure proper design, operation, and maintenance of these small onfarm plants.

Ethanol may also be produced from wood, grasses, and other lignocellulosic sources by producing fermentable sugars through acid or enzymatic hydrolysis, and then fermenting and distilling in a manner identical to that used for grain and sugar feedstocks. Aside from the initial step, the impacts also would be identical. Because presently available processes are not particularly efficient, future processes for

*See "Fermentation" in vol. II

**Assuming 10,000 Btu/kWh

large-scale ethanol production may be significantly different in design, with uncertain impacts. The waste streams of the present processes do not present any unusual control problems.

Methanol Production

There are no facilities for converting wood (or other lignocellulosic feedstock) to methanol in the United States, and a detailed environmental analysis is not available. Nevertheless, the components of the process–wood gasification, various types of gas and water effluent cleanup, and conversion of synthesis gas to methanol — are moderately well understood, and the general environmental difficulties that may be associated with a methanol plant are predictable.

In contrast to the ethanol distillation plant, very little of the energy required for the methanol production process is supplied by external combustion sources; most of the energy is obtained from the heat generated during gasification of the feedstock and from the final methanol synthesis step, and the comparisons to similarly sized powerplants used for ethanol distillation are irrelevant.

The gasification process, which is the major source of pollutants, will generate a variety of compounds such as hydrogen sulfide and cyanide, water, carbonyl sulfide, tars and oils containing a multitude of oxygenated organic compounds (organic acids, aldehydes, ketones, etc.), aromatic derivatives of benzene (such as phenols), and particulate matter. The concentrations of most of these pollutants are dependent on process conditions, and improved control of the gasification process may be an important pollution control mechanism.

As with low-Btu wood gasification (see "Wood Fuel Cycle"), air quality concerns of a biomass-to-methanol plant focus on accidental leakage rather than stack emissions. The small concentrations of toxic inorganic and organic compounds in the gas stream from the gasifier will make raw gas leakage a substantive occupational hazard if good plant housekeeping is not maintained. On the other hand, cleanup of the gas stream would be necessary even without strict air quality regulations, because the final methanol transformation step requires an extremely pure input gas (the pollutants would poison the catalysts and reduce plant efficiency).

The water effluent may also require sophisticated controls to avoid damage to water quality. It appears likely that most plants will attempt to capture and recycle the tars and oils in this effluent in order to produce additional synthesis gas. The remaining pollutants have not been characterized adequately, but they will include a variety of oxygenated hydrocarbons as well as small amounts of phenols and other benzene derivatives. Some of the pollutants may be controlled adequately with standard industrial treatment methods — aerated lagoons, or biological reactors similar to those used in refineries. More sophisticated controls may have to be used for the remaining pollutants, but the necessity for such controls is not clear at this time.

Alcohol Use

Blends.– The effects of alcohol-gasoline blends on automotive emissions depend on how the engine is tuned and whether or not it has a carburetor with feedback control. Because the emission changes are extremely mixed (some pollutants increase and others decrease), it is difficult to assign either a beneficial or detrimental net pollution effect to these blends,

The use of alcohol-gasoline blends will have the following effects on the emissions of most cars on the road today: 40

- increased evaporative emissions, although as much as half of the new emissions are not particularly reactive and should not contribute significantly to photochemical smog;
- decreased emissions of polynuclear aromatics (proven for methanol blends only);
- decreased emissions of CO;
- increased emissions of aldehydes, which are reactive and conceivably may aggravate smog problems; and

[40] H. Adelman, R. K. Petley, et al., op. cit.

- **increased** NO_x emissions with decreased emissions of exhaust hydrocarbons, or decreased NO_x with increased hydrocarbons (depending on the state of engine tune).

Emissions changes involving CO, aldehydes, exhaust hydrocarbons, and NO_x will be considerably less in automobiles that are automatically adjusted to maintain air-fuel ratios.

Pure Alcohols. – In contrast to the ambiguous emission effects of the blends, the use of pure alcohols as gasoline substitutes will have a generally positive effect on emissions. Although aldehyde emissions would increase significantly in cars without oxidation catalysts, substantial reductions in other **reactive** hydrocarbon and NO_x exhaust emissions will occur with methanol and, to a lesser extent, with ethanol. Particulate emissions and polynuclear aromatic compounds are reduced virtually to zero with methanol, and similar effects are expected with ethanol. This effect is especially significant if the alcohols are substituted for leaded gasolines, which create higher and more toxic particulate emissions than unleaded gas.

Diesels. – Few data are available to allow the prediction of emission changes from the use of alcohol fuels and blends in diesel engines. A likely effect, however, is the reduction of particulate emissions. This would not only ease the problems of auto manufacturers in meeting particulate standards but conceivably could allow the use of oxidation catalysts to improve control of hydrocarbon emissions.

Gas Turbines. – Although tests in unmodified turbines have been conducted, few experimental data exist on which to base predictions of the emissions effect of using alcohol fuels on a suitably designed gas turbine. Methanol use in an automotive turbine has produced a tenfold increase in hydrocarbon emissions, but this may be inapplicable to an optimally designed engine.[41] The most significant expected effect is a substantial drop in NO_x emissions, which can be a problem in gas turbines; methanol should be more effective than ethanol in this regard,

[41] C. W. LaPointe and W. L. Schultz, "Comparison of Emission Indices Within a Turbine Combustor Operated on Diesel Fuel and Methanol," SAE paper No. 730669, June 1973.

Social Impacts

The widespread production and use of alcohol fuels can be expected to bring a number of social and economic changes, including effects on employment, health and safety, food and land prices, and ethical considerations. Those impacts that could accompany the production of ethanol from grain are discussed below. Social and economic changes associated with the use of wood for methanol and with grasses and residues for either fuel alcohol are discussed in their respective fuel cycle sections.

A number of different kinds of workers would be required if grain ethanol production were increased. For example, it would take approximately 11,5 million to 15 million hours of farm labor to produce enough corn for 1 billion gal/yr of ethanol. (Comparable productivity estimates are not available for grain feedstocks other than corn.) Workers also would be needed for the transportation of feedstocks to distilleries and of ethanol to refineries or gasohol distributors, as well as for the manufacture and delivery of fertilizer, pesticides, farm machinery, and distillery equipment, and for the construction and operation of distilleries. Estimates of the number of distillery operating, maintenance, and supervisory personnel required to produce 1 billion gal/yr of ethanol from corn range from *920* to 3,100, depending on the size and number of distilleries. Comparable figures are not available for distillery construction or for the manufacture of distillery equipment.

The production of distillery fuels also would require labor on farms or in coal mines. The use of cellulosic materials to fire distillery boilers would require additional farm labor, but not on the same scale as would the production of corn for ethanol feedstocks. These are discussed in detail in the next section. Alternatively, if distilleries are fueled with coal, approximately 290,000 to 465,000 underground coal mine worker shifts or 95,000 to 155,000 surface mine worker shifts would be required to produce 1 billion gal/yr of ethanol, depending on the type of coal and the size of the distilleries.

It should be noted that estimated labor requirements in agriculture are very uncertain. Crop production is highly mechanized and labor requirements have declined continuously since 1950. If farm labor productivity continues to increase, the estimates given above are high. Other uncertainties are introduced by the projected method of increasing production; more labor usually is required to expand the number of acres in production than to increase the output per acre, and some crops require more labor than others. Moreover, during peak farm seasons, such as planting and harvesting, agricultural labor often is scarce. Emphasizing crops that require less intensive management and that are harvested at different times of the year from conventional food and feed crops (e. g., grasses) could alleviate this problem.

The impacts of new employment depend in part on where it occurs and in part on whether the jobs are filled by residents or in-migrants. Onfarm employment and new jobs associated with distillery operations (except for jobs requiring special skills) probably will involve long-term rural residents. Farmers who would prefer to produce at full capacity will consider the increased labor a benefit. In addition, in rural areas with declining economies, new jobs could reduce off-farm migration, shift the age distribution in rural areas to a younger population, and revitalize small farming communities; these could strengthen the rural family and farming as a way of life. On the other hand, distillery construction is more likely to involve temporary immigrants or commuters. Although these workers may temporarily increase demand for some goods and services, their impact is not expected to be significant.

However, with these potential benefits come several drawbacks. First, both commercial-scale and onfarm grain ethanol production can pose health and safety hazards. The incidence rate of reported occupational injuries and illnesses in agricultural production is 25 percent higher than the average rate for all private industries. Unless safer farming methods are developed, increasing agricultural output to meet energy demand could increase the number of farm accidents. Onfarm stills also pose a safety hazard; leaks in the distilling system can result in fires and explosions. Additionally, onfarm stills represent a source of cheap beverage alcohol, one that is especially attractive to minors because of its accessibility. The alcohol may contain poisons, including fusel oil, acetaldehydes, and methanol, that can cause liver, kidney, and brain damage as well as blindness, but these contaminants can be avoided easily and inexpensively by careful distillation and filtration through activated charcoal. If significant amounts of the ethanol produced onfarm were consumed, it would seriously undermine U.S. policy to tax alcoholic beverages.

In addition, increased ethanol production could have significant effects on the price of food and farmland. As noted earlier, using grain for ethanol could inflate farm commodity prices. Increased farm commodity prices would, in turn, result in increased farmland prices that could make it more difficult for new farmers to enter the business and could increase the proportion of farmland under corporate ownership.

Increased corn prices also would increase the price of meat and other foods. This increased price falls disproportionately on the poor and reduces their purchasing power relative to other income groups still further. In addition, increases in U.S. food prices are likely to increase the price of food on the international market. Some countries will not be able to afford food imports, and others will export crops now used domestically for food or feed or switch production to crops that can be exported.

Finally, the increased production and use of gasohol will intensify the conflict between food and energy uses of land. In the United States, this conflict has revolved around the use of prime agricultural land for surface mining as well as energy uses of water in the arid regions of the West. Increased demand for farm commodities to be used for domestic fuel will heighten this conflict because fuel production can compete directly with U.S. food and feed exports. If food exports were reduced significantly in order to augment U.S. energy supplies, adverse foreign responses might result. The use of farm commodities for ethanol also could compete with domestic consumption of food and feed, and dietary habits could change, for example, from marbled beef to range-fed beef or to sources of protein other than red meat.

Crop Residues and Grass and Legume Herbage

Introduction

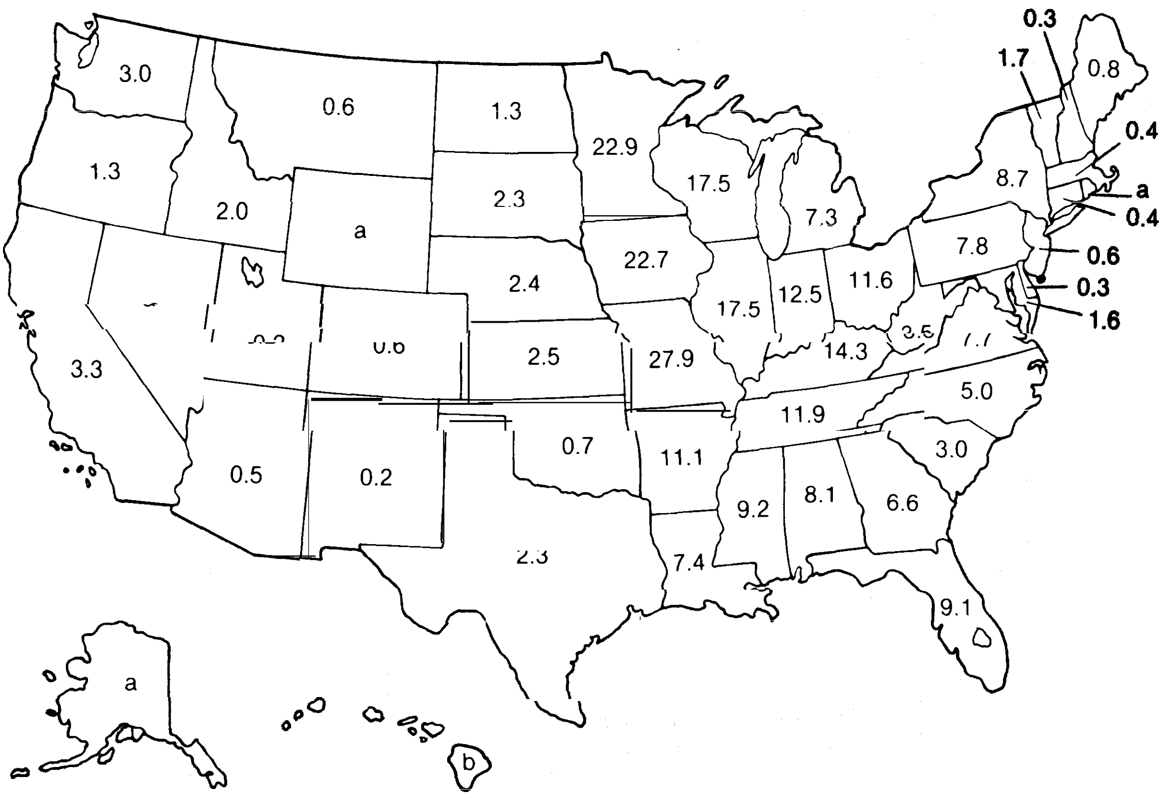
Crop residues and grass and legume herbage are discussed together because they have similar physical and chemical properties, they both occur in the farming regions of the United States, and farmers can harvest them for energy and additional income. For the sake of simplicity, the use of "grass" or "lignocellulose crop" refers to both grass and legume herbage.

It should be noted, however, that these are not the only sources of lignocellulose material for energy production. Indeed, such lignocellulose plants as short-rotation trees also may yield "high quantities of dry matter per acre. Only the energy potential of grasses is analyzed here, however, because grass is readily attainable in the near term from existing agricultural operations without major environ mental or economic disruptions.

OTA's analysis indicates that crop residues could supply 0.7 to 1.0 Quad/yr. The energy potential of grasses is somewhat greater —l.3 to *2.7* Quads/yr in the short term and perhaps as much as 5 Quads/yr by 2000, depending on cropland needs for food production.

Although crop residues and grasses constitute negligible energy supply sources at present, they have the potential for making a noteworthy contribution to the bioenergy supply (figure 31).

Figure 31 .—Usable Crop Residues and Potential Near-Term Herbage Production (million dry ton/yr)



[a]Less than O 1

[b]The major source is sugarcane bagasse which is normally harvested with the sugarcane Thus this arises as a sugarcane processing byproduct and is currently burned to generate electricity and supply process steam to the sugar refineries

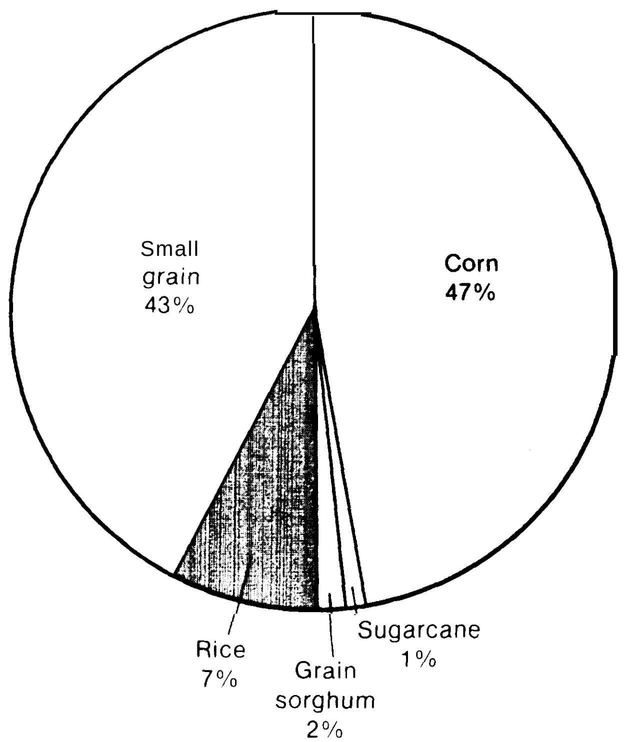
SOURCE. Off Ice of Technology Assessment.

Technical Aspects

Crop residues are the materials left in the field after harvest–stalks, leaves, and other organic debris. About 5 Quads of crop residues are left on U.S. cropland each year (figure 32). Over 80 percent of this, however, is needed to protect the soil from erosion or would be lost during collection and storage, which leaves 1.0 Quad/yr on the average. In addition, crop yield fluctuations can reduce the quantity that can be removed safely from year to year. When these reductions are accounted for (by assuming a plus or minus 20-percent local fluctuation in crop yields), the reliable supply of crop residues is about 0.7 Quad/yr. Consequently, the potential supply of crop residues for energy is estimated to be about 0.7 to 1.0 Quad/yr. If food production increases by 20 percent in 2000, than the usable crop residues would total about 0.8 to 1.2 Quads/yr.

Figure 32.—Crop Residues by Type

Total usable residues = 78.2 million dry ton/yr



SOURCE: Office of Technology Assessment.

To compensate for the loss of soil nutrients that result from crop residue removal, farmers will have to fertilize their land more intensively at an estimated cost of $7.70/ton of residue removed. Furthermore, the harvesting of residues delays the fall plowing. In years when winter rains come early, the fall plowing may be impossible. When this happens, the spring planting is delayed (because of the additional time needed in the spring plowing) and, if corn is being grown, yields will decline. Using computer simulation of the actual weather conditions in central Indiana from 1968 to 1974, it was estimated that this would decrease the corn yield by 1.6 bu/acre on the average, costing the farmer about $2.70/ton of residue. * Other crops, however, are less sensitive to the exact planting time and, consequently, are less likely to suffer from this problem.

Normally many of the crop residues are plowed under during the fall plowing. This practice renders them useless as a protection against soil erosion. Removal of some of the crop residues would allow various types of farming practices that actually could reduce the soil erosion (see "Environmental Effects").

Most of the usable crop residues are located in the most productive agricultural regions of the Midwest and California, Washington, and Idaho (see figure 31). The average quantities available in States having a potential of more than 0.015 Quad/yr are shown in table 11.

Currently about 125 million acres of pasture and hayland in the eastern half of the United States have sufficient rainfall to support increased grass production. About 100 million acres of this could be harvested. * Current practices usually limit the annual forage grass production to about 2 to 3 dry ton/acre of grass. (This supplies sufficient grass to cover the feed and bedding needs for which this grass currently is used.) By applying fertilizers to this land and harvesting the grass one or two additional times, farmers can increase their harvested grass yield by about 1 to 2 ton/acre-

*See Agriculture in vol. II.
**See Agriculture in vol. II.

Table 11.—Average Crop Residue Quantities Usable for Energy

State	Quantity (million dry ton/yr)	(Quads/yr [a])
Minnesota	10.2	0.13
Illinois	9.0	0.12
Iowa	8.5	0.11
Indiana	6.2	0.08
Ohio	3.8	0.05
Wisconsin	3.7	0.05
California	3.3	0.04
Washington	3.0	0.04
Kansas	2.5	0.03
Nebraska	2.4	0.03
Texas	2.3	0.03
Arkansas	2.3	0.03
South Dakota	2.3	0.03
Idaho	2.0	0.03
Michigan	1.7	0.02
Missouri	1.6	0.02
Oregon	1.3	0.02
North Dakota	1.3	0.02
Other	10.8	0.14
Total	*78.2*	1.02

[a] Assumes 13 million Btu/dry ton
[b] Sums may not agree due to round off error Estimated uncertainty ± 20%
SOURCE Office of Technology Assessment

yr on the average. This could result in 100 million to 200 million ton/yr of grass or about 1.3 to 2.7 Quads/yr. (After deducting the energy needed for cultivation and harvesting, this corresponds to 1.1 to 2.2 Quads/yr). The estimated quantities of forage grass that could be harvested for energy in the near term are shown in table 12 for those States with a capability of over 0.015 Quad/yr.

By 2000, anywhere from zero to 65 million acres of marginal cropland could be available for energy production.[42] This range corresponds to an uncertainty of less than plus or minus 10 percent in the cropland needs for food production in 2000, so it is unlikely that more accurate projections can be made 20 years into the future. Assuming average annual grass yields of 6 ton/acre on this land, anywhere from O to 5 Quads/yr of grass could be available for energy.

[42] O. C. Doering, op. cit.

Table 12.—Potential Excess Grass Production, Assuming 2-Ton/Acre Annual Production Increases"

State	'Quantity (mill Ion dry ton/yr)	(Quads/yr)[b]
Missouri	26.2	0.34
Iowa	14.2	0.18
Wisconsin	13,8	0.18
Kentucky	13.6	0.18
Minnesota	12.7	0.17
Tennessee	11.5	0.15
Mississippi	8.8	0.11
Arkansas	8.8	0.11
Illinois	8.5	0.11
Florida	8.5	0.11
New York	8.2	0.11
Alabama	8.1	0.11
Ohio	7.8	0.10
Virginia	7.3	0.09
Pennsylvania	6.8	0.09
Indiana	6.3	0.08
Louisiana	6.3	0.08
Georgia	5.9	0.08
Michigan	5.6	0.07
North Carolina	4.0	0.05
West Virginia	3.4	0.04
South Carolina	2.7	0.04
Vermont	1.7	0.02
Maryland	1.2	0.02
Other	2.6	0.03
Total [c]	204.5	2.66

[a]Assumes additional production on all hayland, cropland pasture, and one-half of noncropland pasture in areas with sufficient rainfall to support the increased production
[b]Assumes 13 million Btu/dry ton
[c]Estimated uncertainty ± 30 'o

SOURCE Office of Technology Assessment

Crop residues and grasses can be made available with existing technology. They can be burned directly or together with coal, converted to an intermediate-Btu gas, converted to various liquid fuels, or gasified in anaerobic digesters (figure 33) Some crop residues, such as rice straw, have special problems (e.g., high silica content that can create a sandblast effect and cause excessive equipment wear); their use may require specialized development efforts.

Grasses and crop residues are quite bulky. Therefore, their most economic use generally will be in the area where they are produced. Processes to concentrate these materials into pellets or similar materials could redeveloped but they will add to the costs of the fuel.*

*See "Thermochemical Conversion" in vol. II

However, the convenience of using the pellets may outweigh the added cost.

Direct combustion of the residues together with coal (cocombustion) has been tested and found to work satisfactorily. In most cases, however, the residues or grasses currently cost more than the coal they replace. While the grasses and residues are low in sulfur, leading to a reduction in sulfur emissions with cocombustion, the decrease is not sufficient in most cases to translate into an economic advantage.

Grasses and residues also can be burned as the sole fuel for a boiler or home heating. But, their bulkiness may be a constraint in some applications, although there is little experience to judge the severity of this problem.

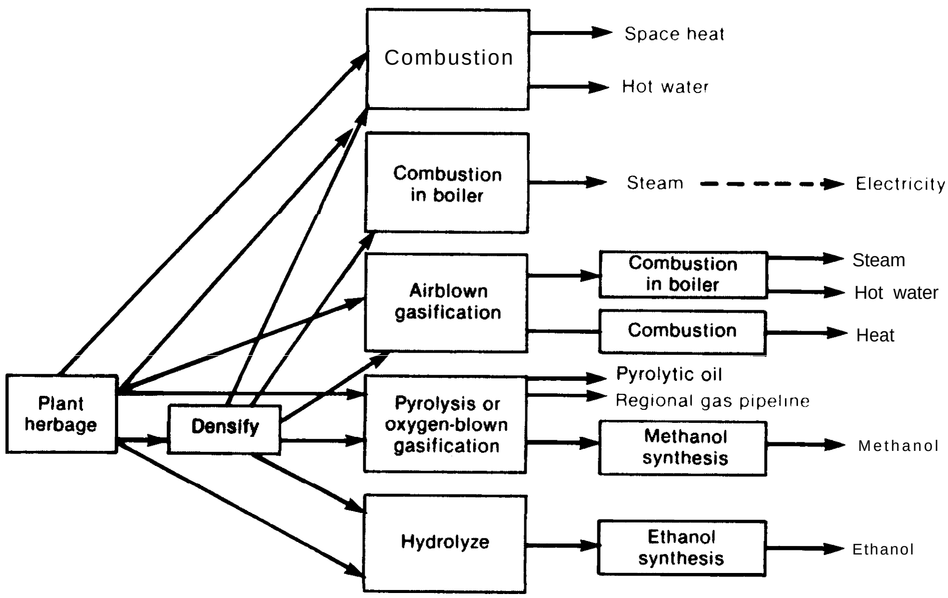
Grasses and residues also can be gasified (by partial or incomplete combustion) in intermediate-Btu gasifiers currently under development. The resultant fuel gas could be burned in retrofitted oil- or natural gas-fired boilers. Users could then revert to oil or natural gas without additional cost if temporary shortages of grasses or residues develop and the other fuels are available. A major problem with grass is its tendency to bridge and clog in the reactor, but with adequate development support suitable gasifiers (and possibly pretreatment) could be commercially available in *2* to *5* years.

The gas from gasifiers also could be used for drying crops and other process heat needs. However, farmers would have to be assured of reliable operation that would under no circumstances pollute the grain with tars, oils, or particulates. Gaining the operating and engineering experience required for these assurances may take somewhat longer than for boiler retrofit gasifiers.

Gasifiers also have been used in the past to fuel internal combustion engines with wood and charcoal. If used in a diesel engine, some diesel fuel is still required to ignite the fuel gas. However, spark ignition engines can be converted completely.

The principal use in engines is likely to be for crop irrigation pumps, where the farmer would fill the gasifier once a day with residues

Figure 33.—Conversion Processes for Herbage



SOURCE: Office of Technology Assessment

Photo credit: USDA, Bill Marr

Irrigation pumps can be fueled with gas derived from biomass for the day's pumping. The principal disadvantage with use in internal combustion engines is that the gas must be cooled before entering the engine (in order for sufficient fuel gas to be drawn into the combustion chamber and to prevent misfiring). The cooling process removes considerable energy from the gas, thereby lowering the overall efficiency and raising the costs. Nevertheless, if grass and residue gasifiers are developed, they could be competitive with some alternative irrigation pump fuels.

Crop residues and grasses also can be converted to methanol, ethanol, and pyrolytic oils with processes completely analogous to those described under "Technical Aspects" of Wood Energy. Methanol conversion appears to be the nearest term option, but facilities require demonstration with these feedstocks primarily because of the feeding and handling problems mentioned above. The other processes for liquid fuels could be commercially available by the mid- to late 1980's with adequate R&D support.

Untreated crop residues generally do not digest well in anaerobic digesters, which produce biogas—60 percent methane (i. e., the same chemical as natural gas) and 40 percent CO,. (Manure is more digestible and is discussed in the next section.) Some types of grasses (e. g., Kentucky blue grass), however, do digest well and could be used as feedstock for anaerobic digesters, but little development work has been done on digesters aimed at these grasses. Consequently, the costs or technical problems for such digesters are largely unknown.

With grasses at $30/dry ton, however, the feedstock cost alone would run about $4.60/million Btu. Thus, it probably would be prohibitively expensive to sell the gas produced from grass in anaerobic digesters to natural gas distributors (after removing the CO,) in the near future. However, increased natural gas prices could change this situation.

Alternatively, digester gas could be used for direct combustion or to fuel internal combustion engines. Both processes, however, should be compared to the (partial combustion) gasifiers considered above. Because the (partial combustion) gasifiers are considerably more efficient than current anaerobic digestion (85 v. 50 percent), relatively dry feedstocks like grasses can usually be used more economically in (partial combustion) gasifiers if the product is to be burned. The low efficiency of (partial combustion) gasifiers when used to fuel internal combustion engines would put the two alternatives on a more equal footing. Moreover, biogas stores well and is easy to use. Under some circumstances, therefore, digestion of the grasses may be attractive relative to (partial combustion) gasification. Further work on the anaerobic digestion of grasses and crop residues is needed, however, before unambiguous choices can be made.

Economics

Obtaining incremental supplies of herbage beyond current requirements for livestock feed and bedding will cost $30 to $40/dry ton ($2.30 to $3.10/million Btu)[43] not including any charge for the use of the land. In the case of residues, land rent should be paid by revenues from the primary product. Additional supplies of herbage can be made available through higher yields with more intensive management and there should be no additional rental charge for these incremental supplies.

[43] S. Barber, et al., "The Potential of Producing Energy From Agriculture," Purdue University, West Lafayette, Ind., contractor report to OTA, May 1979.

The economics of herbage fuels are quite similar to the economics of wood, the other major source of lignocellulose for energy. Lignocellulose of all kinds — and especially herbage — is of low quality compared to fossil fuels due to its low energy content per pound, bulkiness, high water content, and perishability. The low energy content and bulkiness require that the point of end use be near the fuel source. Hence, local market imbalances cannot be rectified easily by regional integration. On the other hand, herbage is a decentralized, renewable, and domestic energy source with the advantage, compared to oil, that supplies are not likely to be disrupted for political reasons. They can, however, be interrupted by unpredictable weather patterns, both during crop growing seasons and along transportation routes between producers and intermediate processors and end users. Because herbage is a bulky, perishable fuel, it also is more difficult to stockpile as insurance against fuel supply interrupt ions.

The inferior fuel characteristics of herbage also dictate higher costs for end users. Because it is bulkier, costs for conversion equipment and for machinery to handle herbage can be expected to be somewhat higher than for wood. Consequently, the load factor, or the number of hours a year equipment is operated, is more important in spreading capital costs over many Btu of output. As an extreme example, assume that capital costs for a herbage gasifier per million Btu are 1.5 times as large as for wood (see table 4). At a 90-percent load factor, the capital cost per million Btu would be $0.75. Decreasing the load factor then leads to an increase in capital costs that is also 1.5 times as great as for wood, making capital a larger factor in the total energy costs.

When both of these economic conditions (location and load factor) are favorable, end users can afford to pay the farmer up to $70/dry ton ($5.40/million Btu) for herbage, assuming that the alternative is fuel oil at $0.90/gal. This fuel value compares favorably with production costs of between $30 and $40/dry ton ($2.30 and $3.10/million Btu) for incremental supplies of either type of herbage beyond current requirements for livestock feed and bedding. It is important to emphasize, however, that costs vary greatly among local areas.

To obtain several Quads per year of energy from these two sources would require prices higher than $40/dry ton, but the necessary incentive is impossible to estimate precisely. In any case, as demand for food expands, while the land base stays the same, the cost of producing lignocellulose will increase due to higher land rents, which must be paid to meet competition from food and feed crops, or due to lower productivity per acre as herbage crops are relegated increasingly to less productive land.

Those most likely to pay premium fuel prices for lignocellulose are industrial process heat or steam users because they can obtain high load factors. If oil fuel prices continue to rise as expected, locating industrial plants **in agricultural areas will** become more and more attractive.

Farmers are the next most likely end users because they have advantages similar to those of the forest products industry in the use of fuelwood. Farm applications generally would not have high load factors. But many farmers already produce herbage for feed and bedding, so they have the necessary handling equipment and expertise. Using herbage for energy on farms also would cut transportation costs and eliminate final transaction costs. That is, the farmer need not accept wholesale discounts on produce sales nor pay retail markups on purchased energy inputs. Moreover, farm vulnerability to fuel supply interruptions would be reduced.

Gasification technology for crop herbage is especially important for initial onfarm applications, such as corn drying and irrigation pumping. Aside from its fuel-switching capability, the intermediate-Btu gasifier can be coupled to existing combustion technology with very little loss in performance. In corn drying, the fuel gas can be combusted and the exhaust gases blown through the grain for drying. In water pumping, the fuel gas can be used in existing combustion engines with only minor changes but, as mentioned above, the cost (per Btu) would be higher than in process heat applications because of lower conversion efficiency. Once gasifiers have become familiar machinery on farms, various other applications may evolve, especially space heating for hog farrowing, poultry, and farm homes.

Environmental Effects

The conversion of grasses and crop residues to energy can substitute for oil and natural gas (through close-coupled gasification or conversion to methanol) or coal (by cofiring with coal or used by itself as a boiler fuel) and thus must be credited with the benefits associated with forgoing the use of these fuels.

Obtaining the Resource

Although the collected grass and crop residue resources are comparable in value as energy feedstocks, the impacts of growing and harvesting them are dissimilar.

Grasses.– Although large quantities of grasses probably would be obtained by intensified production measures–regularly fertilizing and harvesting several times a year— the impacts of growing and harvesting grasses for energy are likely to be less severe than those associated with crops such as corn — the major gasohol feedstock. Grasses are perennial, close-grown crops. As discussed in volume 11, intensive production of grasses, in contrast to annual row crop production, is not expected to lead to significant increases in erosion because the root systems of grasses survive after harvest, grasses provide more coverage of the soil, and grass production does not require erosive cultivation. At the present time, pesticide use on grasslands is virtually nonexistent. Although it is possible that the added stress caused by multiple harvesting could lead to intensified need for pesticides on these lands, the lower level of runoff and erosion will reduce the loss of pesticides and other chemicals to surface waters, Finally, most or all of the intensive grass production will occur on land that is now in some sort of grass production, and major ecosystem changes are not expected. (However, a portion of present grass production is in pasture, is not mechanically harvested, and supports wildlife that may not survive if the grass crop is mechanically fertilized and harvested several times per year.) In conclusion, unless the stresses on the grassland ecosystems from intensified production are greater than expected, the environmental impacts associated with obtaining substantial quantities of grass feedstocks should be relatively mild. This conclusion is predicated on the assumption that intensive grass production will **not** encroach to a great extent on lands that are now in forest or other high-value environmental use.

Crop Residues.– The environmental effects of collecting large quantities of crop residues for use as an energy feedstock are complex, largely because the residues currently are treated in a variety of ways—they are, alternatively, left as a cover on the soil, plowed under after the harvest, collected, or burned in place–and, when allowed to remain on the land, they have a variety of positive and negative effects that would be eliminated or moderated with collection.

The most widely recognized attribute of crop residues left in place on the land is their ability to reduce soil erosion. For example, erosion may be cut in half on conventionally tilled land when the residue is left in place as a protective cover.[44] The important role of residues in erosion control accounts for concerns that their collection may lead to increased farmland erosion.

For a number of reasons, these concerns should be tempered. First, much of the erosion protection is lost **anyway because the residues often are routinely** plowed under or removed. Although it can be argued that these practices could be altered in the future, most are done for economically rational reasons. For example, as noted above, retention of residues on the surface will hinder soil warming and thus delay spring planting, which in turn decreases yields in corn. In some areas and with some crops, retention leads to “poor seed germination, stand reduction, phytotoxic effects, nonuniform moisture distribution, immobilization of nitrogen in a form unavailable to plants, and increased insect and weed prob-

[44] W. E. Larson, et al., “Residues for Soil Conservation,” paper No. 9818, Science Journal Series, U.S. Department of Agriculture, Agricultural Research Service, 1978.

lems."[45] Second, a substantial portion of the residues that currently are retained apparently **can** be removed (according to SCS calculations)" without significant erosion damage. If farmers can be convinced to follow SCS guidelines, erosion increases from residue removal should be minimal. Third, in some cases removal of a portion of the residues makes herbicidal control of weeds more effective and therefore encourages adoption of minimum tillage systems which lead, in turn, to reduced soil erosion.

Unfortunately, the present economic incentives for soil conservation are weak. Farmers may tend to respond to the short-term monetary benefits of harvesting residues that are needed for erosion control. Substantial increases in cropland erosion (and, as a consequence, increased sediment damages to lakes and streams) could occur if residue collection for energy is encouraged without providing strong incentives for farmers to follow erosion control guidelines.

A second potential impact of widespread collection of crop residues is associated with decreases **in** soil organic content. The reduction of soil organic content has been identified as a significant impact of residue removal,[47] and soil scientists have long thought that soil organic content is a critical variable in the health of the agricultural ecosystem (e.g., increasing the organic content of soils can stimulate the growth and activity of soil micro-organisms that compete with plant pathogens). However, despite a variety of papers in the agronomy literature that treat yield as a function of soil organic level,[48] there is insufficient experimental evidence to establish that any significant effects on crop yields would occur if these levels declined. Also, the much higher yields of today's agriculture mean that removal of half of the residue will leave the same amount of organic material as would have occurred 25 years ago if **all** of the residue had been left on the land. Although the long-term danger associated with reductions in soil organic content clearly deserves further research, it appears to have been assigned a level of certainty in excess of that warranted by the scientific evidence.

An additional impact is the effect of the increased need for chemical fertilizers caused by residue collection. Although such fertilizers can compensate for the depletion of nutrients in the residues, they pose some additional risk of nutrient losses to surface and ground waters.

Conversion

The gasification of grasses and crop residues to produce an intermediate-Btu gas should have impacts similar to those experienced with wood gasification, described earlier. In general, air pollution problems are more likely to arise from leaks of the raw product gases rather than from later combustion of the gases. The raw gases may contain ammonia, hydrogen sulfide and cyanide, and polynuclear aromatic compounds, all of which could cause occupational hazards. Water effluents from the gasifiers will be high in biological oxygen demand, and tar byproducts may be carcinogenic. However, the present lack of experience with gasifiers makes any impact projections speculative.

Conversion of these materials to ethanol will have impacts that are identical to those described earlier for a corn-to-ethanol distillery except for the initial transformation of the materials to sugars suitable for fermentation, Because present processes do not appear to allow these lignocellulosic materials to be competitive with corn for ethanol production, the final forms such processes may take— and their impacts— are uncertain. Present processes have waste streams with concentrations of calcium sulfate, calcium chloride, or other materials, most of which are not particularly

[45] *Improving Soils With Organic Wastes* (Washington, D.C.: U.S. Department of Agriculture, 1978).

[46] For example, see W. E. Larson, "Plant Residues—How Can They Be Used Best," paper No. 10585, Science Journal Series, U.S. Department of Agriculture, Agricultural Research Service, 1979.

[47] For example, see D. Pimentel, et al., "Land Degradation: Effects on Food and Energy Resources," *Science*, vol. 194, Oct. 8, 1976, also *Environmental Development Plan*, Biomass Energy Systems, op. cit.

[48] For example, R. E. Lucas, et al., "Soil Carbon Dynamics and Cropping Practices," in *Agriculture and Energy*, William Lockeretz, ed. (New York: Academic Press, 1977).

toxic. As discussed in the earlier section on gasohol, major ethanol impacts include air pollution –especially particulates-–from boilers to power the distillery, and a high biological and chemical oxygen demand effluent that requires careful disposal.

Conversion to methanol, as described in "Alcohol Fuels, " will generate some toxic air and water pollutants requiring sophisticated controls as well as good plant housekeeping.

An important energy use for grasses and crop residues may be their direct combustion, either alone or in combination with coal, for the generation of heat, steam, and electricity. For example, the widespread use of corn for ethanol may be accompanied by the use of the corn residues to power the distilleries. Because of the lower combustion temperature and low levels of sulfur and fuel-bound nitrogen in the feedstock, the burning of grasses or residues may yield low nitrogen and sulfur oxide and moderately high carbon monoxide air pollution levels. Particulate levels could be high if, as with wood combustion, significant amounts of particulate hydrocarbons are emitted, The larger combustion units should be able to control particulate with electrostatic precipitators or other devices as well as by maintaining high combustion efficiency (which will also control carbon monoxide formation). High combustion efficiency may be difficult to maintain, however, if the boiler was originally designed for coal or if a wide variety of feedstocks is used.

Social Impacts

Both grasses and crop residues could have significant employment effects. Intensive management of grasses resulting in yields of 3 to 5 ton/acre-yr would require from 29,000 to **43,000** workdays per 0.1 Quad/yr. Labor requirements for harvesting residues and moving them to the roadside range from 0.3 hour per acre for corn or grain sorghum collected in large stacks to 2.5 hours per acre for rice residues collected in bales (table 13). Actual labor needs would depend on whether the grasses were used in distillation or combustion facilities, Collecting residues need not add significantly to farm labor, but could create new business for custom operators who work under contract to farmers who either do not have access to the necessary equipment or do not have time to harvest residues.

Table 13.—Labor Requirements for Harvesting Collectible Residues (work hours/acre)[a]

	Large round bales	Large stacks
Corn	0.7- 0.8	0.3- 0.4
Small grains	0.5- 0.6	0.4- 0.5
Grain sorghum	0.5- 0.6	0.3- 0.4
Rice	1.5- 2.0	—
Sugarcane	2.0- 2.5	—

[a]Assumes use of current technology

SOURCES Stanley E Barber et al 'The Potential of Producing Energy From Agriculture OTA contractor report May 1979 and the Off Ice of Technology Assessment

As with the farm labor requirements for gasohol, the labor needed to produce forage grasses and crop residues for energy probably would involve long-term residents and would be regarded as a benefit among farmers who feel they are underproducing or who would welcome the added income from each crop.

Additional employment increases associated with the production of forage grasses and crop residues for energy include transportation to the conversion facility as well as the manufacture of farm machinery, fertilizer, and other agricultural inputs. Finally, employment would arise in the manufacture and distribution of conversion equipment and the construction and operation of facilities. The labor requirements for ethanol or methanol plants using grasses or residues as feedstock would be similar to grain ethanol distilleries; these are discussed in "Alcohol Fuels. " The labor needs for constructing and operating cocombustion facilities would be comparable to coal- or wood-fired plants and are discussed in the wood fuel cycle.

The principal economic impact associated with energy from grasses and residues is the increase in farm income attributable to the sale or use of energy products. Where the grasses and residues are on small tracts, their use for energy would enable small farmers to use their land more fully and thus remain competitive.

Favorable farm attitudes toward increased production of forage grasses and the harvesting of residues for energy will be necessary. In general, the demand for these materials or education programs that demonstrate the net profitability of these practices, given their labor, fertilizer equipment, and energy inputs, would be sufficient to convince farmers to adopt them.[49] In some cases, however, the commercial potential of grasses and residues would have to be substantial in order to demonstrate to farmers a need to change their traditional grass management and residue-handling methods.[50]

[49] Fred Pampel, Jr., and J. C. van Es, "Environmental Quality and Issues of Adoption Research," *Rural Sociology* 42 57, Spring 1977

[50] *Use of Crop Residues to Support a Municipal Electric* [illegible] Final report to the Ozarks Regional Commission (Kansas State University Center for Energy Studies No 41, 1977)

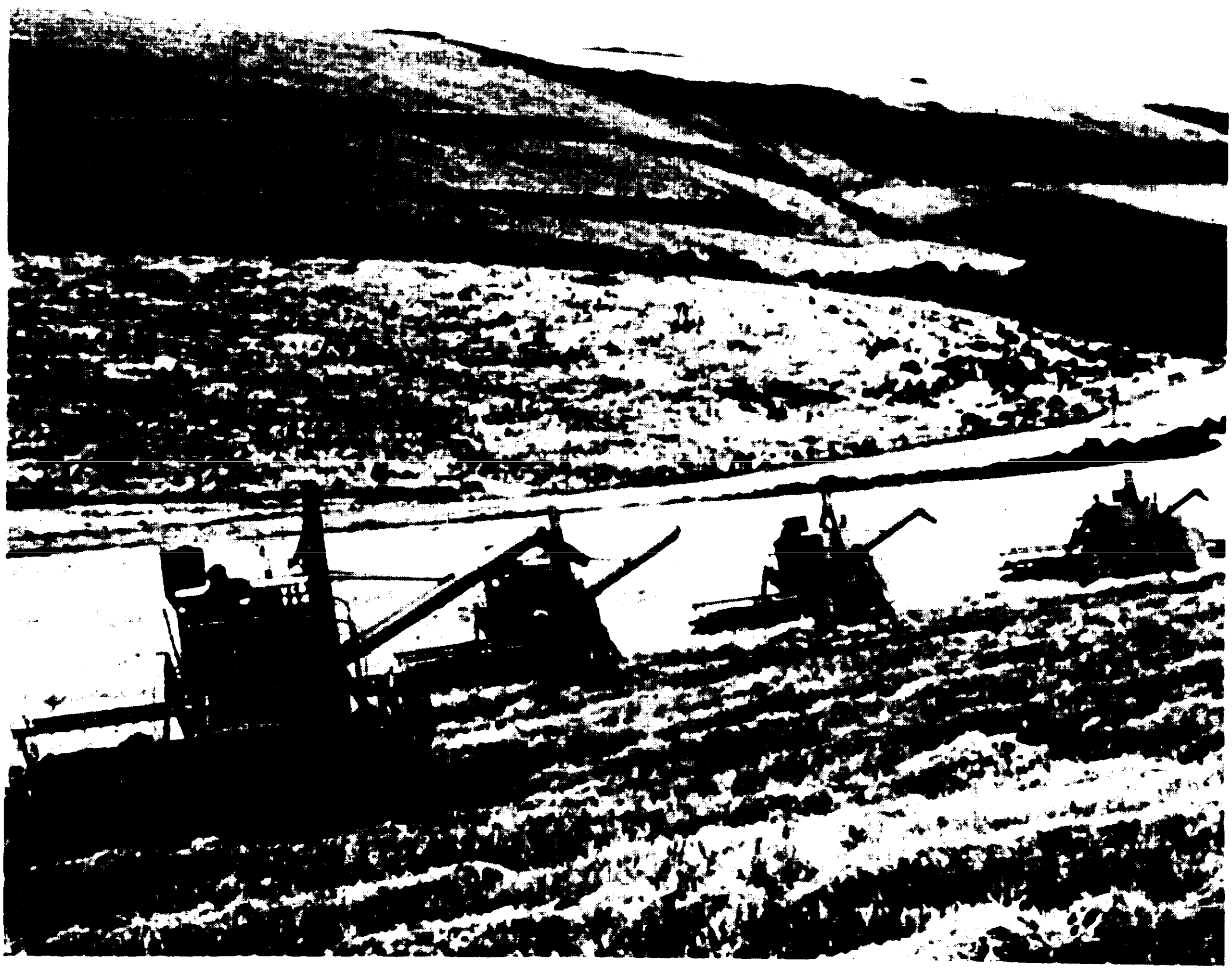


Photo credit: Department of Energy

Harvesting activities would contribute to increased farm employment

Anaerobic Digestion of Animal Wastes

Introduction

OTA estimates the energy potential of chicken, turkey, cattle, and swine manure to be about 0,2 to 0.3 Quad/yr. However, the benefits of anaerobic digestion of manure are greater than this figure suggests. Besides producing biogas, anaerobic digestion is a waste treatment process and the effluent can be used as a soil conditioner (low-grade fertilizer), dewatered and used for animal bedding, and perhaps even as livestock feed.

This analysis has centered around digestion of animal manure on relatively small confined livestock operations and on digesters suited to these needs. Other applications, such as municipal sewage treatment, are subject to different conditions and limitations that usually dictate different types of digesters. Also, very large applications such as the largest feedlots and kelp digestion will have the option of using more technologically sophisticated digester systems. These and other possibilities are considered in more detail under "Anaerobic Digestion" in volume II.

Photo credit USDA

All kinds of confined animal operations could benefit from anaerobic digestion of wastes

Technical Aspects

Anaerobic digestion occurs when biomass is put into a chamber without access to air. Bacteria consume the biomass and, in the process, release biogas—a mixture of 40 percent CO_2 and 60 percent methane, the principal component of natural gas.

Crop residues and wood are usually poor feedstocks for anaerobic digestion, although pretreatments can improve their digestibility (table 14). The best feedstocks are various aquatic plants, certain types of grass, and animal manure. The supply of aquatic plants is likely to be small in the 1980's and the cost of producing grasses (see "Crop Residues and Grass and Legume Herbage") usually will make biogas production from them uneconomic at present. Consequently, the most promising near-term application of anaerobic digestion is with animal manure as the feedstock.

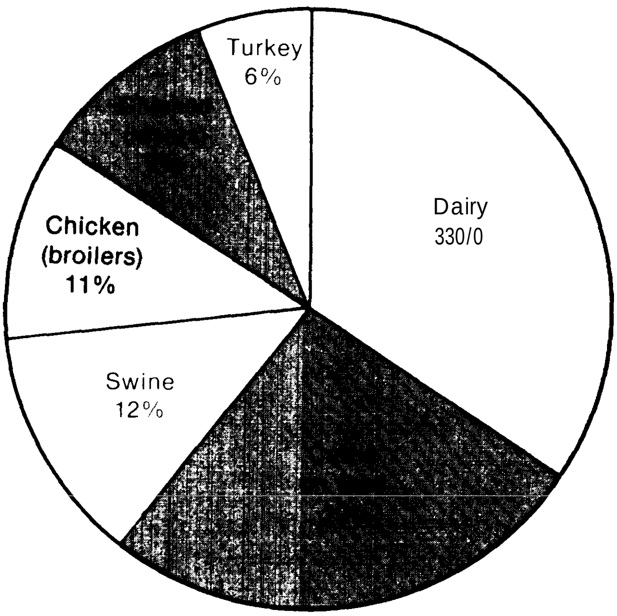
Table 14.—Characteristics of Various Substrates for Anaerobic Digestion

Feedstock	Availability	Suitability for digestion	Special problems
Animal wastes			
Dairy.	Small- to medium-sized farms, 30 to 150 head	Excellent	No major problems, some systems operating
Beef cattle.	Feedlots, 1,0OO to 100,000 cattle	Excellent	Rocks and grit in the feed require degritting, some systems operating
Swine.	100 to 1,000 per farm	Excellent	Lincomycin in the swine feed will inhibit digestion—full-scale systems operating on university farms
Chicken	10,000 to 1 million per farm	Excellent	Degritting necessary, broiler operations need special design due to aged manure, tendency to sour
Turkey	30,000 to 500,000 per farm	Excellent	Bedding can be a problem, manure is generally aged, no commercial systems operating
Municipal wastes			
Sewage	All towns and cities	Excellent	Usually too dilute for efficient net energy yield, vast experience
Solid wastes	All towns and cities	Organic material other than plastics very good	Need separation facilities on the f rent end, commercial system in operation, digests slowly
Crop residues			
Wheat straw . .	Some cropland	Fair, perhaps better suited to direct combustion	Particle size reduction necessary, low digestibility, no commercial systems
Corn stover	Some crop land	Fair, perhaps better suited to direct combustion	No commercial systems, no data available, particle size reduction necessary
Grasses			
Kentucky blue. .	Individual home lawns	Good	Distribution of feedstock disperse, no commercial systems, digests slowly
Orchard grass. . .	Midwest	Fair	No commercial systems, no data on sustainability of yields
Alfalfa	Throughout the United States	Good	No data
Aquatic plants			
Water hyacinth .	Southern climates very high reproduction rates	Very good	No commercial operations, needs pregrinding
Algae	Warm or controlled climates	Excellent	
Ocean kelp	West coast, Pacific Ocean, large-scale kelp farms	Excellent	Full-scale operations not proven, no present value for effluent
Various woods . . .	Total United States	Poor, better for direct combustion or pyrolysis	Will not digest
Kraft paper . . .	Limited	Excellent, need to evaluate recycle potential and other conversion processes	Premixing watering necessary

SOURCE T Abeles, D Ellsworth, and J Genereux, "Biological Production of Gas, " contractor report to OTA, April 1979

OTA estimates that about 0.27 Quad/yr of biogas could be produced if all the animal manure in confined livestock operations were digested.* Assuming that 15 percent of this output is needed to operate the digester, the net output would be about 0.23 Quad/yr. This estimate includes manure from laying hens, broilers, turkeys, dairy cows, cattle on feed, and swine (figure *34),* Although the manure handling techniques used for about half of the manure make it unsuited to anaerobic digestion (because it is allowed to dry or significant quantities are allowed to wash away by rain), these techniques probably will change if anaerobic digestion becomes economically attractive.

Figure 34.—Types of Animal Manure From Confined Animal Operation



Total energy potential =
0.2 -0.3 Quad/yr

SOURCE: Office of Technology Assessment from K. Smith, et al., "Animal Wastes," contractor report to OTA, March 1979

A more serious limitation, however, is the size of many confined livestock operations. Like other conversion technologies, there is an economy of scale in anaerobic digestion. About 75 percent of the manure resource is on animal operations of 1,000 head of cattle or less (or the equivalent for other animals such as swine, turkeys, chickens, and dairy cows), and 50 percent is on operations one-tenth this size or smaller. Only 15 percent of the manure resource occurs on large feed lots of the equivalent of more than 10,000 head of cattle. Because manure cannot be economically transported for long distances, exploiting the manure resource will require digester designs suitable for relatively small animal operations. Important features of these digesters will be automatic operation and low installation costs.

Several companies offer digester systems for onfarm use. Helping to demonstrate a large range of designs using different manure types and different sized operations, however, could improve the flexibility and reliability of digesters. Furthermore, alternative digester types may be developed, which could lower the capital investment. *

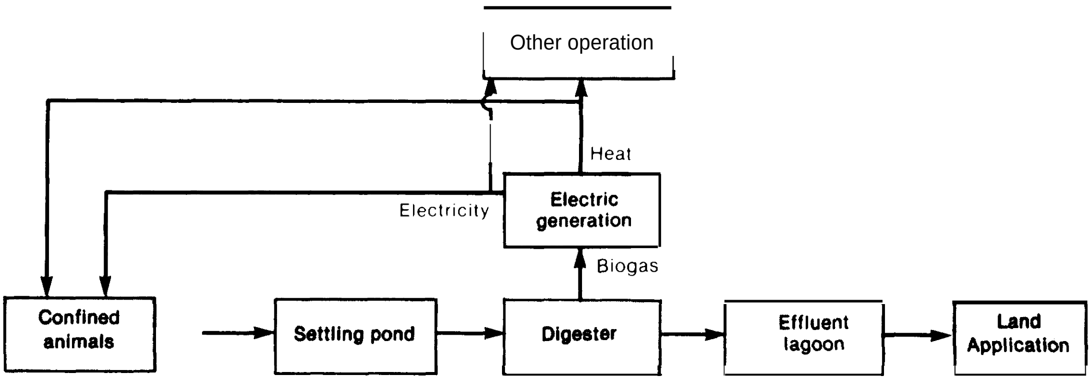
In a common digester system (figure 35), a settling pond is used to store the manure prior to digestion. The digester consists of a long tank into which the manure is fed from one end. After several weeks, the digested manure exits at the other end and is stored in an effluent lagoon. Gas exits from the top of the digester tank, the small hydrogen sulfide content is removed if necessary, and the biogas is used to fuel an internal combustion engine that drives an electric generator. The system supplies electricity for onsite use and for wholesale sales to the electric utility. The heat from the engine is used onsite with any excess heat going to waste.

There are other possibilities for digestion systems. On relatively large operations near existing natural gas pipelines, the CO_2 can be removed from the biogas and the methane sold to the pipeline company. In some cases, it might be introduced into pipelines without removing the CO_2 if it is diluted sufficiently with high-Btu natural gas. Alternatively, the gas could be used only for heat, but generally there are not enough heating needs associated with livestock operations to make full use of the biogas, and the costs would be prohibitive.

*Substantial quantities of manure are also voided from grazing animals, but it is usually not economic to collect this manure

*See Anaerobic Digestion, vol. II.

Figure 35. —Anaerobic Digester System



SOURCE Office of Technology Assessment

Livestock operations, however, might be able to use or sell the gas for nearby applications, such as greenhouse heating.

The digester effluent can be used as a fertilizer, just as manure sometimes is. The effluent also can be dewatered and sold as a fertilizer, or used as animal bedding or as an animal feed supplement for its protein content. The animal feed option, however, needs further testing to determine if the effluent is a suitable feed and, if so, what its value is. There also is an issue of which digester types produce the most suitable animal feed.

The system analyzed in detail in this report has sufficient gas storage capacity to vary the electric generation to match daily peak electric demands. If proper farm-utility interfaces are developed, the utility could control the times that electricity is being fed into its system by sending coded signals along the power transmission cables or telephone lines, or through other load management techniques. In many cases, however, this could require some adaptation of onfarm energy use to the utility's needs. Both the interface problem and the overall effect of decentralized electric generation on the utility operation will be dealt with further in a forthcoming OTA assessment of dispersed electric generation.

The total quantity of electricity generated would be relatively modest. If half the manure resource were digested and the resultant biogas used to generate electricity with an (assumed) efficiency of 20 percent, the total electric generation would be only slightly more than 1,000 MW of capacity. At the same time, about 0.08 Quad/yr of heat would be produced. The principal impact would be on the livestock operations themselves. Many livestock operations could become energy self-sufficient and some would have the opportunity of expanding into energy-intensive enterprises such as vegetable or flower cultivation in greenhouses or possibly onfarm or cooperative ethanol distillation.

Economics

Unlike the three preceding fuel cycles, and especially in contrast to ethanol from grain and sugar crops, biomass energy from manure would not compete directly with the production of other commodities. Rather, biogas digestion makes better use of an existing resource without destroying its value for other purposes. Digester effluent is at least safer to reject into the environment than raw manure and it may be preferred as either a fertilizer or an animal feed, although this has not been fully established.

However, the economics of digestion remain unclear due to limited commercial experience in the United States. The fact that it is economical in other countries, where labor costs are much cheaper and where standards of material comfort are much lower, does not imply that comparable technologies will penetrate American agriculture. One reason for limited commercial experience is that farmers are reluctant to adopt a new technology that requires a large initial investment. It is perhaps the most extreme example of biomass capital intensity considered in this report.

Rising prices for purchased fuels, however, will make digestion more attractive. Also, as an onfarm energy resource, biogas would tend to insulate farmers from some fuel supply interruptions. Finally, biogas may become economical as a result of environmental quality standards that force farmers to sanitize manure wastes before rejecting them into the environment.

In deciding whether or not to install a digester for its energy product, economic calculations depend heavily on three aspects of livestock operations. First, there must be a minimum amount of manure suitable for digestion, so that high capital costs can be spread over a sufficiently large product stream, lowering the cost per unit of energy obtained. Second, onfarm utilization of biogas, either by direct combustion or indirectly by electric generation, enhances its value by displacement of purchased energy at retail prices. The alternative is selling electricity to utilities at lower, wholesale rates. Third, to displace the maximum amount of purchased electricity, the rate of nonfarm electricity y consumption should have a steady (base load) component, assuring a high load factor for generating capacity. Sales to electric utilities may offset an irregular load pattern, but if many farmers with the same load characteristics try to sell their excess power at the same time its wholesale value could be low.

Looking at digestion for its biogas product alone, its first widespread application may be on large poultry farms in the northern tier of States. Poultry manure from this region accounts for between 15 to 20 percent of the potential energy in manure resources. Digesters must be able to accommodate the high solids content of this manure as well as some associated inert material (grit), but unusual economic opportunities exist because biogas displaces premium liquid fuels and electricity for heating, lighting, feeding, and manure collection. In highly controlled poultry environments, all activities related to biogas production and use can be coordinated and equipment sized for maximum load factors. Poultry farming was the first type of animal husbandry to be automated and, for the same reasons, it may be the first to generally adopt manure digestion if appropriate digester systems become available.

Among the other types of livestock farming (beef, dairy, and swine), no one type has a clear overall advantage over the others in the adoption of digesters. Each type of operation has both advantages and disadvantages.

Beef feeding may be an attractive application because thousands of head often are kept in adjacent pens, making it possible to use highly specialized equipment for manure collection, digestion, and for storage and disposal of digestion products. On the other hand, the energy in beef manure is much greater than the amount of energy used by the feedlot. Moreover, feed lot energy consumption is concentrated during short periods of feeding and manure cleaning, and the fuel used is often gasoline or diesel (for tractors and trucks to distribute feed and to remove manure) which biogas cannot displace easily. Furthermore, if the feedlot is not hard surfaced, manure may dry out quickly or be contaminated with soil, gravel, and other nondigestible material. Despite these disadvantages, digestion may still be economical for large lots that are highly electrified, that have sufficient volume to justify upgrading gas to pipeline quality, or that can combine digestion with ethanol distillation, In the latter case, the biogas would provide the heat of distillation and the distillers grain might be fed wet to the cattle, thus avoiding drying costs. An alternative to digestion, for the same purpose of supplying energy to a distillation process, would be to combust dried manure. The latter approach may be preferred if the value of the digester effluent were insignificant and the pollution and other problems associated with manure combustion were adequately solved

Swine farming has an advantage in colder regions of the country in having a more or less continuous demand for space (or floor) heating during cold months. Heating is especially important at farrowing time and while pigs are young. Electric power demand for automated feeding may also be nearly continuous as pigs are often self-fed. That is, they are allowed to eat as much as they want, whenever they want. Although hog operations are growing steadily in size over time, they remain relatively small compared to poultry and beef farms and consequently cannot take advantage of similar economies of scale.

Dairy farms have an advantage in using large quantities of hot water year round that could be heated by the direct combustion of biogas. They have, however, many of the same disadvantages of beef operations. Much more energy exists in the manure than is needed by the dairy operation and the rates of use are concentrated around milking time, mainly for running compressors (used by milking machines and bulk tank coolers) and for lights. Dairies also are likely to be even smaller than hog operations because the hired labor necessary for very large operations is generally not sufficiently motivated to achieve maximum milk production.

It should be emphasized that all cost estimates are extremely site specific, but it is clear that digestion currently is an expensive source of energy if all digester costs are charged to the biogas product alone. For the most profitable poultry operations, capital costs are equivalent to oil at $60,000 to $100,000/bbl/d of capacity, or about twice the capital costs of Alaskan North Slope oil. If 20 percent of the energy in biogas were converted into electricity, and all capital costs were charged to electricity (i. e., no use of waste heat), then the cost per kilowatt of electric power generated would be about $3,500, or about three times the capital cost of electricity from coal. These high capital costs make it difficult for farmers to experiment with new technology.

Byproduct credits for waste treatment could lower these costs significantly (see "Environmental Effects"). In fact, digested manure for refeeding to livestock could turn out to be more valuable than biogas. The necessary feeding experiments have not been done but the payoffs could be large if effluent protein were considered equivalent to protein in existing feed supplements. Taking into account that about 30 percent of manure weight is lost in digestion, the economic value of manure feedstock could be increased from between $0 to $20/dry ton at present to between $40 to $70/dry ton.

Environmental Effects

Anaerobic digestion of animal manure generally is viewed as an environmentally beneficial technology because it is actually an environmental control process to reduce pollution from feed lots and other confined animal operat ions. The energy product — biogas — is a byproduct of the control process, which converts the raw manure, often a substantial disposal problem, into a lews harmful sludge material.

The environmental benefits associated with reducing pollution from confined animal operations are extremely important. The runoff from these operations is a source of high concentrations of bacteria, suspended and dissolved sol ids, and chemical and biological oxygen demand. Runoff from cattle feedlots has caused large and extensive fish kills because of oxygen depletion of receiving waters; high nitrogen concentrations in ground and surface waters, which can contribute to the aging of streams as well as to nitrate poisoning of infants and livestock; transmission of infectious disease organisms (including salmonella, leptospirosis, and coliform and enterococci bacteria) to people, livestock, and wildlife; and coloring of streams.[51]

[51] R. C. Loehr, *Pollution Implications of Animal Wastes — A Forward Oriented Review* (Washington, D.C.: Environmental Protection Agency, July 1968), EPA report 13040-07/68.

The major problem associated with the digest ion process is waste disposal and the associated water pollution impacts that could result. As noted above, anaerobic digestion is basically a waste treatment technology-it breaks down the organic (volatile) solids initially present in the manure. However, although the process reduces the organic pollution content of manure, it does not eliminate it. The *combination* of liquid and solid effluent from the digester still contains organic solids as well as fairly high concentrations of inorganic salts, some concentrate ions of hydrogen sulfide (H_2S) and ammonia (NH_3), and variable amounts of metals such as boron and copper that may be toxic to plants.[52] (The composition of the waste stream depends on the diet of the animals as well as the efficiency of the digester) For operations where the manure is collected only intermittently, small concentrate ions of pesticides used for fly control may be contained in the manure and passed through to the waste stream.

A variety of disposal options exist for the liqu id and sludge wastes of anaerobic digestion. Generally, wastes will be ponded to allow settling to occur. The liquid, which is high in organic content, can be pumped into tank trucks (or, for very large operations, piped directly to fields) to be used for irrigation and fertilization, although the high salt content and small concentrations of metals in the fluid make it necessary to rotate land used for this type of disposal. Large operations may conceivably treat the water and recycle it, but the treatment cost may prove to be prohibitive. Other disposal methods for the liquid include evaporation (in arid climates), discharge into waterways (although larger operations are likely to be subject to zero discharge requirements by E PA), and discharge into public sewage treatment plants. Where the liquid deliberately or accidentally comes in contact with porous soils, contamination of the ground water system is possible. As with virtually all disposal problems of this nature, this is a design and enforcement problem rather than a technological one; for example, evaporation ponds can be lined with clay or other substances to protect ground water resources.

The organic content of the liquid effluent, which varies according to the efficiency of the digester, will present a biochemical oxygen demand problem if allowed to enter surface waters that cannot dilute the effluent sufficiently or that do not have additional assimilative capacity. Similar problems can occur with organics leached from manure storage piles. However, this problem exists in more severe form in a feedlot or other operation that has no anaerobic digester.

The sludge product can be disposed of in a landfill, but it appears that the sludge has value either as a fertilizer or cattle feed. Successful experience with anaerobically digested municipal sludges (with higher metals concentrations) as fertilizer imply that the sludge should present no metals problem.[53] In areas where chemical fertilizers are unavailable or too expensive (e. g., in the developing countries), the retention of the manure's fertilizer value is a particularly critical benefit of the biogas process,

Although the H_2S (and related compounds) content of the effluent may present some odor problems, this problem, as well as that of the very small pesticide content, should be negligible.[54]

Pollutant concentrations caused by biogas combustion should be of little consequence to public health. Although the biogas does contain small (less than 1 percent each[55]) concentrations of H_2S and NH_3, neither should pose a problem. NH, is oxidized to NO_x in fairly low concentrations during combustion. H_2S forms corrosive sulfurous and sulfuric acids and must be scrubbed out before combustion in order to allow the gas to be used. Fortunately, simple and inexpensive scrubbing methods are available.

[52] *Solar Program Assessment*, op cit

[53] *Methane Generation From Human, Animal, and Agricultural Wastes* (National Academy of Sciences, National Research Council, 1977), Library of Congress catalog 77-92794

[54] M C T Kuo and J L Jones, "Environmental and Energy Output-put Analyses for the Conversion of Agricultural Residues to Methane," in *Energy From Biomass and Wastes: Symposium Papers* (Washington, D C : Institute of Gas Technology, Aug 14 18, 1978)

[55] *Solar Program Assessment*, op cit

Leaks of the raw product gas **can** represent an occupational health and safety problem as well as a potential public nuisance, The occupational health problem is related to the H_2S contaminant in the raw gas. The raw biogas can contain H_2S in concentrations of over 1,000 ppm.[56] Although exposure to this full concentration seems extremely unlikely, concentrations of 500 ppm can lead to unconsciousness and death within 30 minutes to 1 hour, and concentrations of 100 ppm to respiratory problems of gradually increasing severity over the course of a few hours. The Occupational Safety and Health Administration's standard is a maximum permissible exposure level of 20 ppm.[57]

Although rapid diffusion of the gas will confine health problems associated with H_2S to occupational exposures, venting of raw gas can cause severe odor problems to the genera l public. In this case, odor problems associated with gas venting should be similar to the more certain odor problems associated with the often haphazard treatment of manure that the biogas operation replaces.

[56]Ibid

[57]Ibid

Because methane is explosive when mixed with air, strong precautions must be taken to avoid biogas leakage into confined areas and to prevent any possibility of the gas coming into contact with sparks or flames. Although this will be a universal problem with biogas facilities, it is particularly worrisome with small units.

The institutional problems associated with assuring that there is adequate control of digester impacts are very similar to those of ethanol plants; it is likely that plants will be small, and thus may have some environmental advantages over larger plants (mainly ease of locating sites for waste disposal and smaller scale local impacts), but will not be able to afford sophisticated waste treatment, are unlikely to be closely monitored, and may be operated and maintained by untrained personnel. Improved system designs are likely if small onfarm systems become popular and the size of the market justifies increased design efforts on the part of the manufacturers. These will probably diminish the safety and health hazards to a certain extent, but the ease and lower cost of building homemade systems coupled with farmers' traditional independence could provide potent competition for the manufactured systems.

Social Impacts

The primary employment increases associated with the use of manure in anaerobic digesters would result from the manufacture, distribution, and maintenance of reliable systems for farm use and in the operation of large feedlot systems. Because so few digesters are currently in use, it is not possible to estimate the additional jobs that would be needed if readily available animal waste were converted to methane, At least 10 firms currently are involved in digester research and engineering; it is not known how many employees they have or how many they expect the digester industry to have in the future.[58] Most confined feeding operations (such as dairy farms and feedlots) already are required by State or local law to collect the animal waste,[59] so the principal new farm labor input to an anaerobic digestion system would be in the operation of the equipment. For the few onfarm and feedlot digester systems now operating, the labor requirements range from 4 hours per week for a small farm digester using 4 ton/d wet manure (100 cows) and producing 2.5 million Btu/d, to 17 people per year for a feedlot system using 340 ton/d wet manure (50,000 head) and producing 570 million to 670 million Btu/d methane.[60]

[58]Tom Abeles and David Ellsworth, "Biological Production of Gas," contractor report for OTA, 1979

[59]George Whetstone, et al., *Analysis of State Laws and Regulations Impacting Animal Waste Management* (Washington, D.C.: Environmental Protection Agency, July 1978), EPA 600 2-78-155.

[60]Abeles and Ellsworth, op. cit

The principal economic impacts of anaerobic digestion would be the reduced farm energy and waste management costs and increased energy self-sufficiency, as well as the potential export value of improved digesters.

Favorable attitudes among farmers toward anaerobic digestion will be necessary for the widespread adoption of this practice. Ensuring favorable opinion is partly a matter of demonstrating that the technology works and is profitable, and partly convincing farmers that they need to change their traditional manure-handling practices. The best predictors of the adopt ion of agricultural innovations are farm capital, size, and sales and the farmer's education.[61] For example, a survey of dairy farmers concluded that those most likely to adopt methane production are under the median age (47), higher than average in education, well informed about the methane potential, have at least 50 cows, and receive gross annual income of over $40,000. However, the dairy farmers considered a methane-production system to be low priority among their possible choices for using capital. Before they would be willing to commit capital they wanted to see working models and to be assured that reliable maintenance and service would be avail able.[62] Thus, the overriding considerations among most farmers seem to be a demonstrated need to change their current farming and waste and residue-handling practices and an operational (nonexperimental), automatic, and relatively inexpensive technology.[63]

[61] Pampel and van Es, op. cit.

[62] K. E. Cole, et al., "A Survey of Worcester County Massachusetts Dairy Farms With Respect to Their Potential for Methane Generation," *Science Technology Review*, September 1979, pp. 27-45.

[63] Ibid.; Abeles and Ellsworth, op. cit.

Bioenergy and the Displacement of Conventional Fuels

The way biomass is converted to useful heat or work will strongly affect its technical ability to substitute for conventional fuels. Currently, the major use is direct combustion in the **residential and industrial sector with a small amount of conversion to a liquid** fuel (ethanol) for use in the transportation sector. Existing technology limits direct combustion to applications such as boilers and space heating. Current policy and economics already are causing a shift away from premium fuels for large commercial and industrial boilers so that biomass will be joining with coal and direct solar in displacing oil and natural gas in these markets, Therefore, a substantial penetration of solid biomass could be at the expense of coal.

For other uses, such as process heat, feedstocks, and transportation, direct combustion of solid biomass is not now technically feasible. Here, the dominant fuels will continue to be natural gas and oil. To use biomass in these applications, either new direct combustion technologies will have to be developed, or conversion to a gas or liquid (alcohol) will be necessary. Therefore, if the major portion of the available biomass fuel supply is to displace significant quantities of oil and natural gas, it will have to be converted to gas or alcohol.

The best way appears to be airblown gasification in terms of thermal efficiency and the range of applications that it allows. There are some limitations here, however, which are related to the low-Btu content of the gas. This puts centralized production and distribution through a pipeline system at a severe economic disadvantage relative to high-Btu natural and synthetic gas, making onsite gasification almost a necessity. Although oxygen gasification would increase the Btu content of the gas, it also would increase the costs.

Methanol production, although less efficient than gasification and direct combustion, does allow use in the transportation sector, and has some advantages over gasification in terms of the economics of transporting the fuel. (The efficiencies may be more comparable, however, if the methanol is used as an octane-boosting additive to gasoline). Unless more detailed economic analysis proves otherwise, a multiple conversion approach may be the best way to maximize biomass use.

While conversion to liquids and gas will greatly expand the potential for biomass to displace oil and natural gas, it will be done in competition with coal. As technologies are put in place for converting the major portion of our biomass resource (wood, grasses, and other lignocellulose materials) into gas or alcohol, technologies for converting coal to gas or liquids will also come onstream. Therefore, the real question will be how does the biomass option compare to coal in replacing oil and natural gas. Besides the important consideration of the relative costs of raw biomass and coal, this choice involves a number of issues that can only be listed here. Many of these points about biomass are discussed in the remainder of this report while some of those about coal are presented in the OTA study *The Direct Use of Coal.*[64] However, no detailed comparative analysis has been made.

The first issue is reliability of supply. The user will want to make sure a long-term, steady supply of the fuel is guaranteed before making a commitment to the necessary conversion or end-use technologies. Second is the necessary environmental controls at the point of use. Which fuel will require the least expensive technologies to burn? Third is collection, transportation, and storage costs. Here the density of the resource, and its proximity are of concern. Fourth is the scale of operation. A small-scale operation with access to biomass may find it more attractive than coal because of the limited quantity demanded. Fifth is the issue of renewability of the resource. If it is determined that the United States must shift to renewable supplies as soon as possible, then biomass may be used even where it now is less economic than coal. Finally, the relative merits of the combustion and conversion technologies must be considered. Gasification of bio-

[64] *The Direct Use of Coal*, op. cit

mass may be less complex and more economical for small-scale operations than coal gasification, and the dispersed nature of biomass will generally limit its application to smaller operations than for coal. However, coal can produce liquids closer to natural crude oil than can be obtained from biomass. Further, coal can produce methanol at a cost that is likely to be less than alcohol from biomass.

In connection with conversion to liquids and gases, it is important to continue efforts to develop new and more efficient ways to convert wood, grass, crop residues, and other lignocellulosic materials to gas and alcohol. Although some processes are commercially ready now, the realization of the full biomass potential will likely require additional developments in these areas.

In a related effort, expansion of bioenergy provides the opportunity to look for ways to use the unique properties of these fuels in altering processes or process steps to increase industrial energy use efficiency. When coal replaced wood in the last half of the 19th century, many industrial processes were changed or developed to take advantage of new properties that coal brought, such as its coking ability. These were largely the result of coal's different chemical properties. There may be analogous opportunities for biomass fuels.

This discussion has indicated some of the general trends and concerns about the potential role of biomass in displacing oil and natural gas. To get a better picture of these considerations, two plausible energy supply and demand futures for 2000 are presented and the way biomass could fit into these futures is discussed. This is done by substituting the maximum available biomass supply into each sector, one at a time, for each future. This is highly unrealistic because considerations such as proximity of supply, transportation and storage of the raw biomass, and environmental control requirements will limit the amount of biomass that could go to any one sector regardless of fuel form. This approach is taken, however, because the way the biomass supply may actually be distributed among sectors could not be projected. The method will give an upper limit. In addition, it is quite likely that costs and time needed for installing the necessary end use and conversion equipment under normal market forces will limit the amount of biomass that could be used to below the maximum available supply. Therefore, this analysis also indicates the technical limit for premium fuels displacement from the major sources of biomass by *2000.*

Current Supply and Demand

In table 15, the 1979 energy demand figures are given by fuel for each sector along with the supply figures by fuel. The numbers are in Quads/yr. These show only the direct fuel input and do not show how much electricity is used by each of the first three sectors. Because bioenergy will be a substitute for a direct fuel, (although it may displace some electricity) this

Table 15.—1979 Energy Picture (Quads/yr)

	Demand sectors				Supply	
Fuel	Residential/ commercial	Industrial	Transportation	Electricity	Domestic	Import
Oil and NGL	6.9	7.4	19.2	3.6	20.5	16.9
Natural gas	7.9	7.8	0.5	3.6	19.2	1.2
Coal	0.2	3.7	—	11.3	17.4	—
Nuclear	—	—	—	2.8	2.8	—
Hydroelectric	—	—	—	3.1	3.1	—
Biomass	0.2	1.3	—	—	1.5	—
Total	15.2	20.2	19.7	24.4	64.5	18.1

SOURCE *Monthly Energy Review* Energy Information Administration. Department of Energy, May 1980 is the most useful way to display energy supply and demand balance.

Currently, biomass contributes about 1.5 Quads/yr, nearly all of which is wood used in the forest products industry. The energy is obtained to a large extent as a byproduct of recovering paper-pulping chemicals. Substantial quantities of wood also are burned for process steam and the most practical current alternatives are residual fuel oil and natural gas. The boilers also could use coal and some do, but wood has a clear economic advantage in this industry due to the need to recover the pulping chemicals in any case and to wood's accessibility compared to coal in most cases.

The other areas where bioenergy is making inroads are transportation (via gasohol) and residential/commercial space heating (wood). The former does not provide any significant substitution for oil or natural gas, partially because the ethanol is not now produced or used in a way to displace the maximum amount of these premium fuels. That is, current distilleries use natural gas as a fuel, and the octane-boosting properties of ethanol, which can reduce refinery fuel use by refining a lower octane gasoline as the gasohol base, are not being fully taken advantage of. OTA's - analysis indicates that the amount of wood used for space-heating is about *0.2* to 0.4 Quad/yr, which principally displaces oil.

Future Supply and Demand

One possible supply-demand picture for *2000* is displayed in table 16. This is based on a forecast given in the report National Energy Plan II (NEP II), by the Department of Energy. This forecast (future A) assumes a world oil price of $38/bbl by 2000 as measured in 1979 dollars. The increases that have occurred this past year, however, make an even higher price quite likely. The effect of this possibility is discussed below. The use of the NEP II forecast does not indicate that OTA endorses it, but rather it is being used solely as a means to explore the potential impact of bioenergy in displacing conventional fuels. An alternative future with considerably lower demand also is presented to see how this changes the potential role of bioenergy.

The major feature in future A of interest to this analysis is the decline in oil use from 1978 levels by all sectors except transportation. This decline would largely be the result of increased efficiency and substitution by coal (either directly or through electricity) and solar. In the residential/commercial and industrial sectors oil would be used for space heating, process heat, and chemical feedstocks. Only in the electric utility sector is any oil used in boilers. Even this estimate may be high if oil prices rise more than this projection assumes, because there will be even greater incentives to convert to coal or phase oil plants out altogether. Natural gas use is projected to increase in the residential/commercial and industrial sectors but decline to zero in the electric utility sector. As with oil, the principal uses will be for space heat, process heat, and chemical feedstocks. The largest use of oil in this projection would be the transportation sector

Table 16.—U.S. Energy in 2000: Future A (Quads/yr)

	Demand sectors				Supply	
Fuel	Residential/ commercial	Industrial	Transportation	Electricity	Domestic	Import
Oil and NGL	3.0	5.0	21.0	2.0	22.0	10.0
Natural gas	9.0	12.0	—	—	19.0	2.0
Coal	—	9.0	—	30.0	39.0	—
Nuclear	—	—	—	17.0	17.0	—
Hydroelectric	—	—	—	4.0	4.0	—
Biomass	0.5	2.5	—	—	3.0	—
Solar	1.0	1.0	—	—	2.0	—
Total	13.5	29.5	21.0	53.0	106.0	12.0

SOURCE. *National Energy Plan II*, Department of Energy where very little conversion to new fuel forms is projected by 2000.

There are a number of uncertainties in future A that may affect the potential for bioenergy. First, domestic oil production is likely to fall well below 22 Quads/yr (11 million bbl/d), leading to greater imports, reduced demand, and/or the need for substitution by other fuels. The possible shortfall could be as much as 6 to 10 Quads/yr. (i. e., production levels of 6 million to 8 million bbl/d), and could virtually remove oil as a fuel for stationary sources if the United States chose not to increase imports and was unable to reduce transportation fuel use significantly.

The second major uncertainty is the nuclear supply projection. Future A shows an increase of nearly a factor of six over current use, to 17 Quads/yr. In light of the economic, environmental, and safety uncertainties now surrounding nuclear power, this increase may be optimistic. If it does not reach this level, the alternatives will be coal-fired electric powerplants, and reduced electric demand (through conservation or direct fuel use).

Other uncertainties involve the amount of natural gas the Nation will produce and the quantity of coal that can be burned. The projections show 19 Quads/yr of natural gas to be produced, which may be high. However, recent discoveries of natural gas plus the potential for unconventional gas resources make this less uncertain than oil.

As for coal, the amount projected can be produced while still meeting current environmental regulations.[65] A major issue here is whether emerging environmental problems such as acid rain and increases in atmospheric CO_2 concentrations will be serious enough to slow down or halt increased coal combustion.

Finally, the demand figures given here probably are higher than will occur. Certainly there is potential for much greater energy efficiency than implied by future A. For example, industrial energy use, including electricity, is forecast to be 36.5 Quads/yr compared to 21.8 Quads/yr in 1978. This is a 2.6-percent average annual increase which compares with the 3.5-percent annual increase from 1960 to 1970, when energy growth was faster than any decade this century, and the 0.8-percent annual increase during the 1970's."

To illustrate the effects of these uncertainties, a second supply-demand future (future B) is presented, in which rising prices, full implementation of cost-effective energy efficiency improvements, and declining supplies of crude oil dampen energy demand growth. Under future B, energy demand is 90 Quads/yr by 2000, compared with 117 Quads/yr in future A or with 1979's 79.4 Quads/yr.

Future B assumes a doubling of current coal use for industry and electric utilities which the OTA coal study states is an easily achievable goal; the operation of only those nuclear plants currently online or under construction; and a direct solar contribution consistent with the base case of the recent Domestic Policy Review of solar energy.[67] In addition a synthetic fuel contribution of 3 million bbl/d is assumed. If the current congressional goal of 2 million bbl/d by 1992 is reached, this figure for 2000 should be easily achieved. This will require an additional 4 to 6 Quads/yr of coal production as well as 2 to 4 Quads/yr of shale oil. The upper bound of 36 Quads/yr of coal (6 for synfuels, 30 for electricity and industry) is still reasonable as expressed in the OTA coal study.

On the demand side, OTA assumes a residential/commercial demand consistent with projections in the OTA study on residential energy conservation,[68] the current ratio of energy use by the residential sector to the commercial sector,[69] an industrial energy use growth rate equal to the 1960-79 rate, and a transportation demand equal to the low-demand case given in future A. The results of this hypothetical future are shown in table 17.

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[65] Ibid.

[66] *Annual Report to Congress, 1978* (vol. II; Washington, D.C.: Department of Energy, Energy Information Administration, 1979).

[67] *National Energy Plan II* (Washington, D.C.: Department of Energy, May 1979), p. VI-4.

[68] *Residential Energy Conservation* (Washington, D.C.: Office of Technology Assessment, July 1979), OTA-E-92.

[69] *Annual Report to Congress, 1978* (vol. III; Washington, D.C.: Department of Energy, Energy Information Administration, 1979).

Again, future B is not meant to be an OTA forecast, but rather a plausible lower energy demand future in which to view the potential contribution of biomass beyond that already forecast (the base biomass contribution given in future A has been maintained). The data in table 17 indicate a much lower quantity of conventional liquids used by stationary sources — about 3.0 Quads/yr.

Table 17.—U.S. Energy in 2000: Future B (Quads/yr)

	Demand sectors				Supply	
Fuel	Residential/ commercial	Industrial	Transportation	Electricity	Domestic	Import
Oil and NGL	1.0	2.0	16.0	—	15.0	4.0
Natural gas	4.5	11.5	0.5	0.5	16.0	1.0
Coal	—	9.0		21.0	30.0	—
Nuclear	—	—		7.0	7.0	—
Hydroelectric	—	—		4.0	4.0	—
Solar	1.5	1.0		1.5	4.0	—
Syn fuel	—	1.5	3.5	1.0	6.0	—
Biomass	0.5	2.5	—	—	3.0	—
Total	7.5	27.5	20.0	35.0	85.0	5.0

SOURCE Off Ice of Technology Assessment

Biomass Potential

Increased use of biomass is now considered by examining the size and nature of the potential supply of bioenergy and analyzing how technically it might fit into the futures just described. To do this the upper limit of the estimates of the potential supply was considered, which is about 17 Quads by 2000. This includes 10 Quads/yr of wood, 5 Quads/yr of grass from haylands and cropland pasture, 1.2 Quads/yr of crop residues, *0.4* Quad/yr of ethanol, 0.1 Quad/yr from agricultural product processing wastes, and 0.3 Quad/yr from animal manure. The estimate for grass from haylands and cropland pasture may be optimistic, because of increased demand for food and feed crops. This upper limit was used, however, to illustrate the technical limits in the displacement of premium fuels.

First, futures A and B, as given above, contain biomass inputs of 0.5 Quad/yr in the residential/commercial sector and *2.5* Quads/yr in the industrial sector. All of this is from wood through direct combustion. OTA believes that existing trends project greater use than this, however, with no additional incentives other than increased prices for alternative fuels. OTA estimates an additional 1.5 Quads/yr in industry, including about 0.1 Quad/yr for crop drying, an additional 0.5 Quad/yr in the residential/commercial sector, about O to **0.4 Quad/yr** in transportation (ethanol from grains and sugar crops–O to 4 billion gal/yr) and about 0.1 Quad/yr from animal manure. This gives a new baseline estimate of about 5.5 Quads/yr total for bioenergy by 2000. Again, the principal contribution would be direct combustion of wood. In this case, the additional 2.5 Quads/yr of bioenergy could expect to displace 1.4 Quads/yr in the industrial sector, about 0.5 Quad/yr of oil or natural gas in the residential sector, about O to 0.4 Quad/yr of oil in the transportation sector, and 0.2 Quad/yr of natural gas and oil in the agricultural sector. The additional bioenergy used in the industrial sector would largely be in the forest products industry to replace oil now used, and for future growth of that industry. In the latter case, the wood probably would be used instead of coal.

Next, consider what would happen if actions were taken to reach the practical limit of the remaining bioenergy supply. As described at the beginning of this section, this analysis is done by applying all of the remaining supply to each sector, one at a time, for each future. Because of the projection that about 5 Quads/

yr from wood will be used without these actions, this leaves about 5 Quads/yr from wood, 6 Quads/yr from grasses and crop residues, plus various smaller contributions from other sources. This is roughly 10 Quads/yr that could be used by direct combustion or conversion to a synthetic gas or liquid (methanol). (The uncertainties in the estimates are too large to warrant greater accuracy in the calculation).

First, direct combustion is considered. Accounting for relative efficiencies of burning biomass and oil, natural gas, or coal, 10 Quads/yr convert to about 9 Quads/yr of net input to final demand. Currently, the average combustion efficiency of solid biomass is about 25 percent less than of coal, oil, or natural gas but higher efficiencies are likely to be the rule in **2000.** First, this 9 Quads/yr are applied to the residential/commercial sector. In the case of future A, this could displace the equivalent amount of oil and natural gas since about 90 percent of the 12 Quads/yr of oil and natural gas projected for that future —10.8 Quads/yr–- is used for space and water heating.* These are the two uses most readily adaptable to direct combustion of biomass. In future B, however, only about 4.0 Quads/yr of the oil and natural gas are used in this sector for space and water heating. Using the entire 9 Quads/yr in this sector, therefore, would mean displacement of a large amount of coal or nuclear electricity and/or direct solar used for space and water heating. Allocating the biomass to industry, in either future, would mostly displace coal. The reason, as described above, is that most of the direct combustion processes for which solid biomass could be used will be using coal by 2000 in either future. Only in future A is there likely to be any oil used for these purposes. Finally, there will be no uses for direct combustion of solid biomass for transportation and any use to generate electricity will displace coal, nuclear, hydro, or geothermal in either future.

In the residential/commercial sector, gasification is similar to direct combustion. Additional uses, such as cooking and clothes drying, could now use biomass, however. Further, gasification, would make retrofits easier and reduce the investment needed to convert to biomass in many cases. Having this option could improve market penetration, but the limits to displacing oil and natural gas would only increase a small amount.

In the industrial sector, gasification of the biomass allows its use for nearly all direct energy purposes for which oil, natural gas, and coal would be used in either of the energy futures. Therefore, biomass could displace large quantities of oil and natural gas used as fuels. To substitute for chemical feedstocks, further synthesis would be required and this is not considered here. Assuming about 40 percent of the oil and natural gas will be used for feedstocks, about 10.2 Quads/yr are needed for fuel purposes in future A.[70] In future B, about 9.0 Quads/yr of the oil and natural gas are needed for fuel purposes. In either future it would be technically possible for all or nearly all of the available bioenergy to be used to displace oil or natural gas in this sector. As stated above, however, synthetic gas from coal will also be available so the real choice is between biomass and coal. It is important to note that the same choice is applicable to the residential/commercial sector where coal gas would also presumably be available.

The final possibility for using biomass is to develop technologies for converting it to methanol. Currently, biomass, in the form of grain, is being converted to ethanol. Conversion to methanol, however, may be a better way to use all forms of biomass resource as a liquid fuel although technologies for converting grasses must still be demonstrated. (Alternatively, economic technologies for producing ethanol from these types of biomass may be developed.) The potential for using biomass in this way is similar to that of gasification in the case of stationary uses. But in this case, conversion losses reduce the incremental 10 Quads/yr of solid biomass to about 4.8 Quads/yr for final demand, which is the least of any form. Equip-

*This percentage is determined from analysis of 1975 residential and commercial energy use data by Oak Ridge National Lab (ORNL/CON-1 and ORNL/CON-15) which is assumed to remain the same in both futures A and B.

[70] This is based on estimates given in *Annual Report to Congress 1978*, vol. III, op. cit.

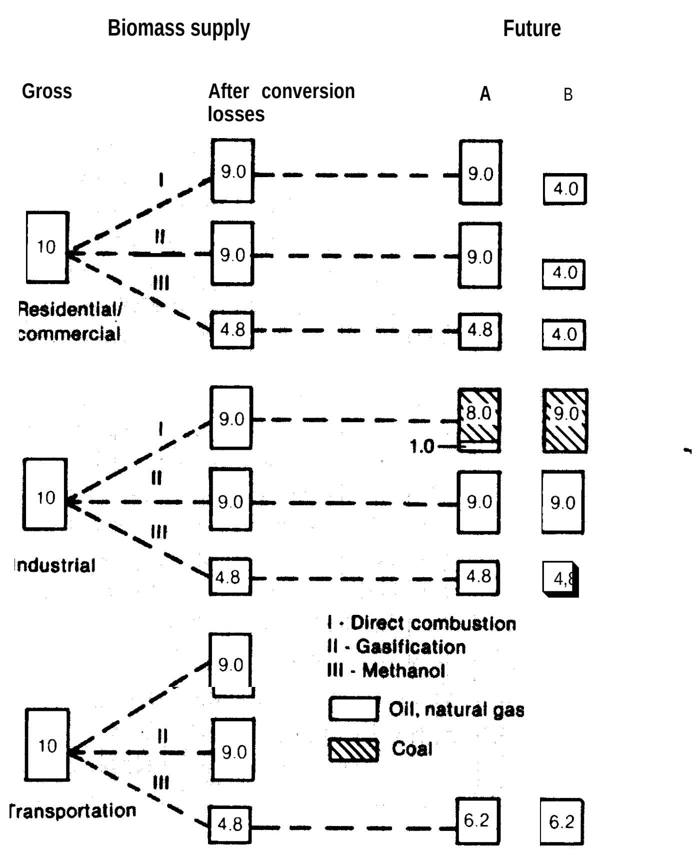
ment modification would also be necessary to account for the different combustion properties of methanol compared to fuel oil, although these should be minor. In this connection, the different combustion efficiencies between methanol and conventional fuels would have to be considered in determining final fuel displacement just as in the case of gasification but these should be small. Again, technologies for converting coal to methanol are also available, so the choice is still between biomass and coal. There are considerations here, however, that were absent in the gasification case. Primary among these are the other liquids that can be produced from coal and oil shale, which in turn can be converted into conventional fuel oils.

The major advantage of conversion to methanol, however, is that it allows all forms of the biomass resource to be a possible source for transportation fuels. If all 4.8 Quads/yr of methanol were used as a standalone fuel, it would be the equivalent of 2.2 million bbl/d of gasoline but OTA estimates that an additional 0.6 Quad/yr of oil displacement can occur from using part of it in blends and 0.8 Quad/yr from its higher efficiency in cars built to use methanol. This raises the total to 6.2 Quads/yr. It would be necessary to make changes in new automobile engines to burn methanol as a standalone fuel. These are not substantial, however, and the same thing would be required for methanol from coal. As with stationary uses, the choice here is between synthetic liquids from coal and from biomass.

Summary

The results of the above analysis are summarized in figure 36 for the three fuel forms of direct combustion, gasification, and conversion to methanol. This figure shows the technical potential for displacing oil and natural gas in the three sectors by allocating the supply of biomass, not already committed, to each sector, in turn, for each future. The results underscore the points raised at the beginning of this section about the limitations of displacing oil and natural gas, the advantages of gasification in making this displacement, and the potential competition with coal, either directly or as a synthetic fuel. The potential for displacement is large, however, and programs designed to use biomass in its three fuel forms—with preference to gasification –and to promote use in all three sectors can probably ensure that a large fraction of our biomass supply will be used to help alleviate U.S. dependence on oil and natural gas.

Figure 36.—Fuel Displacement With Biomass (Quads/yr)



SOURCE Office of Technology Assessment

Chapter 5
POLICY

Chapter 5.-POLICY

TABLES

FIGURE

Chapter 5
POLICY

Introduction

It should be clear from the technical analysis presented in preceding chapters that there is no single "biomass" energy system. Rather there are many technologies that provide means of converting plant matter and animal wastes into usable forms of energy. Some of these technologies, such as wood-burning stoves, are well established in the marketplace, others are being developed, and still others hold promise only for the distant future. This report focuses attention on four fuel cycles, selected according to their technological readiness and their potential to contribute significant amounts of energy. Each of these involves different raw materials, produces different kinds of fuels, and may therefore be expected to respond to different incentives. Accordingly, policy options appropriate to each fuel cycle are discussed in detail in separate sections that follow. All biomass energy forms, however, have some common advantages, and encounter some common difficulties; these are reviewed first.

Consider the advantages. Biomass energy forms are **renewable;** their use can help to relieve pressure on depleting fossil fuel resources. They are also **domestic** and can be expected to reduce American dependence on insecure imported oil, enhance the U.S. balance-of-payments position (except where agricultural exports are reduced), and reduce America's vulnerability to supply interruptions. Insofar as biomass fuels are imported from abroad, they will likely come from non-OPEC countries, such as Brazil, thus diversifying the energy supply pattern. In addition, some biomass energy sources **contribute to the solution of important pollution or waste disposal problems** and most of them are likely to **contribute less to the long-term buildup of carbon dioxide** (CO_2) in the atmosphere than the fossil fuel systems they replace, because biological growth processes consume CO_2, balancing, at least in part, the release of this gas in combustion. *

Depending on the technologies that are adopted and the scale of production chosen, biomass energy **may provide the basis for the growth of small business enterprises** and the **decentralization of economic activity, both of which are valued by many Americans. Finally many of the most important biomass energy technologies are already in use; hence an expansion** of U.S. energy supply from these need not await costly and time-consuming R&D activities.

Despite these clear advantages, biomass fuel cycles face several serious difficulties. Some of these stem from the character of the technologies and their dependence on diverse source materials; others stem from the incompatibility of the fuel cycles with existing energy distribution and production systems.

Perhaps the most serious general problem confronting biomass energy development is that the source materials upon which the fuel cycles rely— wood and agricultural commodities— are often already in use for nonenergy purposes. Demand for these materials for conversion to energy will have important, but difficult to measure, impacts on existing markets. So will the sale of coproducts, such as distiller's grain, that are currently important in assuring the economic viability of bioenergy. Biomass energy forms are thus linked to existing nonenergy markets in a way that most fossil fuels are not. This creates uncertainty regarding economic viability that is unrelated to the adequacy of the technologies themselves. It also complicates the design of policy options because the commodities involved are already affected by laws and regulations that

*Under certain circumstances, such as where deforestation or reduction of soil organic matter occurs, there could be a net CO_2 increase.

have purposes unrelated to, and often conflict with, the goal of energy development. Moreover, in the case of wood and most agricultural products, established Government agencies are involved and their perspectives, administrative preferences, and longstanding procedures must be considered carefully if policies are to prove successful.

The existence of nonenergy markets for biomass also means that in many cases it will be difficult to implement policies that apply only to bioenergy uses of these commodities. For example, if subsidies were offered only for biomass grown on certain lands or only for resources managed according to environmental guidelines, it would be almost impossible to prove which products were grown on those lands or in accordance with those guidelines. Consequently, many policies will have to be implemented throughout the forestry or agricultural systems.

At the other end of the cycle, many biomass technologies produce an energy in quality, form, or quantity that does not readily fit existing energy distribution or consumption systems. This difficulty is enhanced by the fact that bioenergy comes from diverse, small-scale, or dispersed sources. A variety of different, site-specific means of processing, distributing, and consuming the resulting fuels must often be developed to make the energy commercially attractive. All of these add to uncertainty in commercialization and to the burden of planning and administration that accompanies the operation of the Nation's energy system at all level s.*

The economic and technical complexity of biomass fuel cycles and the certainty that they will have extensive, but difficult to predict, impacts on food, fiber, fertilizer, and energy markets, among others, suggest the need for both care and flexibility in the design of policies to promote them. In most cases, their economic attractiveness and impacts can be tested only by experimenting with them and living with them. To be avoided are those policies that commit the country heavily to particular technologies prematurely, or that provide hidden subsidies that obscure the full costs of alternatives and perhaps repress, indirectly, ones that might be more attractive.

The energy markets in which biomass must compete already are very complex, and are affected by layers of regulations, subsidies, and direct and indirect controls that will influence the attractiveness of new products significantly. Thus, in evaluating the actions that might be taken to promote and regulate biomass energy, a first step is to review those policies that currently favor— directly or indirectly–fossil fuels and nuclear energy. These include price controls, special tax treatment for depletion and drilling costs, R&D support, and many other subsidies. A recent study, for example, has concluded that in the years since 1918 the Federal Government has spent more than $217 billion in subsidies and incentives to stimulate the development of conventional energy sources. However, fossil and nuclear fuels are also subject to extensive regulatory requirements designed to protect public health and safety and the environment. In most cases, bioenergy conversion will escape these costs, but harvesting of most biomass resources has a significant potential for environmental damage and occupational injury.

A second step would be to review existing policies that subsidize or discourage the production of biomass source materials, feedstocks, or byproducts. Price supports for agricultural products are an example of these policies. In general, too, any policies that increase the price, or slow the development, of domestic or imported conventional energy sources, can be expected to improve the prospects for biomass. Several existing policies have such an effect, but the most important is phased deregulation of oil and gas prices.

In addition to policies that support biomass energy indirectly, there are a number of initiatives that might provide more direct assistance. Among the most important of these are policies that promote information dissemina-

* Many of these issues will be addressed in greater detail in OTA's forthcoming study of dispersed electric generation

[1]Battelle Memorial Institute, "An Analysis of Federal Incentives Used to Stimulate Energy Production," December 1978, and see Gerard M Brannon, *Energy Taxes and Subsidies* (Cambridge, Mass Ballinger, 1974)

tion and commercialization. information dissemination is especially important in promoting biomass energy because many technical applications are attractive only under site-specific or supply-specific conditions. This is a problem for many renewable energy technologies. The circumstances that make crop residues attractive in a farming community in Arkansas, for example, may be duplicated only in another community in Idaho. How can the information about the different technologies or processes, and their relationship to market conditions, be brought to these disparate operations? With respect to this goal, the experience with the Agricultural Extension Service suggests a useful model,

Commercialization of new technologies is even more difficult. Policies that support commercialization usually are justified on the grounds that technical, economic, and environmental uncertainties, some of them due to Government policies, delay the adoption of many technologies, especially those requiring large capital investments, until increases in energy prices have made them overwhelmingly attractive,

Commercialization policies may take many forms. Some are designed to help establish supply infrastructures, some to assure the availability of capital, and some to reduce the risks associated with conversion to new energy systems. Standard policy instruments to achieve these goals include technical assistance, tax credits, loan guarantees, and the adjustments of regulatory requirements to facilitate the sale of energy or the adoption of new technologies. In some cases incentives such as guaranteed markets or prices have been advocated as well.

In assessing commercialization policies, it is important to distinguish between: 1) those in which the taxpayers absorb initial risks and the Government clears hurdles to the demonstration of technical and commercial feasibility, and 2) permanent subsidies. The first are temporary supports, based on the assumption that bioenergy will stand on its own once it has been introduced, The goal is to bring technologies online more rapidly than would otherwise be the case, with the public paying the price required for a limited period of time. For these policies, attention to specific time and scale limitations is critical in the formulation of legislation.

Outright subsidies, whether direct or indirect, are more controversial and must be weighed with greater care. Subsidies have been, and continue to be, important instruments in energy policy. Proponents of domestic, environmentally acceptable, renewable energy often argue in favor of permanent subsidies on the grounds that they are granted to other energy forms and that the external costs of conventional energy systems make them far more expensive than their market prices suggest. Whether biomass fuel cycles should be subsidized, and if so, how much support is needed to counter the effects of subsidies to fossil fuels and nuclear energy, are political choices that the country must make, The point here is that the country must choose with the understanding that competition among different energy technologies, according to the efficiency and cost of each, will be impaired by permanent subsidies. The Federal Government's lack of experience with commercialization also should be taken into account. Where possible, therefore, it would appear best to promote commercialization with self-limiting subsidies, and then, if they are desired, to choose permanent subsidies that al low different renewable energy forms, including biomass energy, to compete with each other in relatively open markets,

Finally, increasing reliance on biomass for energy usually means tying energy supply to complex markets and to raw materials that either are heavily dependent on weather and climate or can be bid away for other uses. Consequently, fluctuations in the supply of these materials are inevitable and may become a serious problem as biomass begins to account for a larger portion of the national energy budget. Under these circumstances, it would appear appropriate for the Federal Government to explore means, such as establishing buffer stocks of raw materials or even of fuels such as alcohol, to assure continuous and reliable supplies of food and other products used as feedstocks, of coproducts, and of energy.

The following sections review policy options for the production and use of energy from wood, alcohol fuels, grasses and crop residues, and animal manure. Of these, the most complex, and therefore the longest, is the section on alcohol fuels, which describes the substantial body of laws, regulations, and programs that affect the American agricultural system as well as those governing soil erosion and air and water quality, and the analysis of options for liquid fuel end uses. Thus, although both wood and crop residues can be converted to methanol, policy considerations affecting the resource can be found in the sections on wood and crop residues, respectively, while those involving methanol production and use are reviewed in the section on alcohol fuels. The last section of this chapter contains a summary of the key policy alternatives for bioenergy development.

Appendix A reviews the key technological developments that may help bioenergy reach its full potential, while appendix B describes the computer model used to project the effects on the agricultural economy of producing ethanol from corn.

Wood

Introduction

A careful review of the wood resource base and the technologies that are now, and might in the future, be employed to convert it to useful energy suggests that a significant expansion of the contribution of wood to the energy supply stream in the United States is possible in the next two decades. Moreover, it may be possible to accomplish this while protecting the environment and forest resources and enhancing the overall production of commercial timber suitable for nonenergy uses. If this expansion is to occur, especially to the higher figures that might be achieved with a careful development of the resource base, public policy support and guidance will be needed to assist in the development and deployment of technologies; to help new users overcome obstacles to converting to wood energy; and to manage the social, economic, and environmental impacts of greater reliance on forestland for energy as well as for fiber, timber, and recreation.

The primary contributors to an expansion of the use of wood energy will be determined largely by geographic location and by the availability of reliable conversion technologies and stable, competitively priced supplies. Approximately 1 million homes currently use wood as a primary heating fuel and as many as 4 million others may be using wood as supplemental fuel. It appears that as many as 10 million homes may rely partially or totally on wood fuel by 1985, consuming perhaps as much as 0.4 to 0.8 Quad/yr in the process.[2] By taking population growth into account, this figure might reach 1 to 2 Quads/yr. The continued growth of fuelwood consumption for residential heating depends on the continued availability of low-cost firewood and the willingness of consumers to convert to wood use and sacrifice the convenience of oil, natural gas, or electric heating. The development of inexpensive automatic wood-fueled furnaces that use woodchips or pellets might increase the attractiveness of such conversion.

Although it is not widely known, the major use of wood energy in the United States today occurs in the forest products industry, where onsite combustion to produce electricity and process steam contributes over 1.2 to 1.3 Quads/yr, or about 45 to 55 percent of the industry's energy needs. With continued escalation in the price of imported oil, it is possible that the forest products industry would approach energy self-sufficiency by 2000. It would then be using between 2 and 3 Quads/yr of wood energy. If, as seems probable, the forest products industry should double its output in the next two decades (assuming some increases in efficiency), it would be using as much as 4 to 5 Quads/yr. As is the case with residential combustion, this increase appears likely to occur as a result of price incentives alone, and may require few additional stimuli. The rate of conversion depends heavily on the speed at which old oil and gas capacity can be replaced economically and on the commercial availability of intermediate-Btu gasifiers for retrofit on existing oil and gas boilers.

If wood energy use is to grow beyond the level of about 4 to 5.5 Quads/yr, however, wood combustion must be adopted by many users not now familiar with this fuel, especially by those "next to the woods" (other than the forest products industries), and thus within reach of a large supply of fuelwood. It is difficult to estimate the likely market for wood here, but the potential clearly is large, particularly where gasifiers can be used for process heat or added to equipment designed to run on oil and gas, thus adding flexibility as well as a cheaper fuel stream. Also important for the expansion of this market is the establishment of reliable wood fuel supply arrangements — a theme which is returned to in the dis-

[2] Booz, Allen and Hamilton, Inc., *Assessment of Proposed Federal Tax Credits for Residential Wood Burning Equipment* (Washington, D.C.: Department of Energy, 1979).

cussion of policy alternatives. * The introduction of methanol to the Nation's liquid fuel system would create still another source of demand for wood. Depending on the price and availability of imported oil, and on the cost and availability of coal-based methanol, the demand for wood for conversion to liquid fuels may also be very large.

To summarize, the United States may expect to produce at least *4* Quads/yr, and most probably about *5.5* Quads/yr, of energy from wood by **2000.** This assumes world oil prices of at least $30/bbl and no substantial change in current policy orientations, and can be expected to occur primarily as a result of the expansion of wood use in homes and in the forest products industry. Although this represents more than a tripling of current use, it is nevertheless a minimum; much more energy could be obtained from this resource. Steeply rising oil and gas prices, carefully designed incentives, and the rapid commercialization of efficient and reliable gasifiers — all would contribute to this. Under these conditions, between 8 and 10 Quads/yr might realistically be obtained from wood by 2000, provided it is harvested as part of an effective forest management program. Note that OTA estimates that the practical maximum is approximately 10 to 11 Quads/yr (table 18). Much of the expansion beyond 4 to 5.5 Quads/yr would have to take place in the commercial/industrial sector outside the forest products industry and, depending on private and Government decisions concerning liquid fuels, in the transportation sector (wood to methanol and perhaps later to ethanol).

*Currently, utilities produce between 60 and 70 MWe (Mitre, 1979) from wood, and an additional 100 MWe or so are on the drawing boards The overall utility market is limited, however, by the very large amounts of wood required by individual plants and by the need for very secure supply sources

Table 18.— Wood Energy Use in the United States (Quads)

Sector	1979	2000 Business as usual	2000 Vigorous support and high energy prices
Residential	0.2-0.4[a]	1.0	2.0
Forest product industries	1.2-1.3	2.5-4.5[b]	5
Other commercial and industrial	—	0.5-1[b]	3-4
Total	**1.4-1.7**	**4-5.5**	**10-11**

aEstimates of current residential use of wood vary considerably The Wood Energy Institute, on the basis of a survey conducted by the Gallup Organization, has estimated that as much as 50 million cords (0.8 Quad) of wood were burned in 1979
bNonadditive

SOURCE Office of Technology Assessment

Current Policies

Although interest in solar energy of all kinds has grown rapidly in recent years, current Federal programs give wood energy little emphasis or coordinated direction. Nevertheless, wood combustion is likely to be the most important, and perhaps the most cost effective, of the solar conversion technologies in the next two decades. The relative lack of interest in wood energy reflects, first, the continuing Federal emphasis on large-scale, centralized, technically sophisticated energy systems, and second, the belief of many policy makers that, among the solar technologies, wood combustion is well understood and likely to grow anyway, while other technologies are more dependent on direct Government assistance if they are to make a contribution. Thus, funding for current wood energy programs is low– and in some instances declining — and wood energy activities have been poorly coordinated in and among the agencies involved. This orientation has changed to some extent in recent months, especially with respect to program definition and interagency coordination, but plans for funding and staffing suggest that basic priorities have been altered only slightly.

In the following pages, major current policies and programs that affect wood energy are briefly reviewed, beginning with forest policy— largely the responsibility of the U.S. Department of Agriculture (USDA) and its Forest Service– and then energy policy–the responsibility of the Department of Energy (DOE).

Forest Policy

Forest Service policies and programs are especially important in the Western United States where a majority of the forestland is federally administered. In managing this land the Forest Service is guided by a number of broad goals articulated in the Organic Act (1897), the Multiple Use-Sustained Yield Act (1960), the Resource Planning Act (1974), and the National Forest Management Act (1976), among others. Especially important for wood energy is the “multiple use” principle, a long-standing guide to land and timber resource management that is followed by the Forest Service. The goal of multiple use management is to assure the balanced use of forest resources by many interests and to prevent overuse by one or a few economically powerful sectors such as logging and forest products companies. The renewable uses for which the national forests are to be managed are grazing, outdoor recreation, timber, watershed, and wildlife and fish. Note that energy is not one of the statutory uses; to the extent that forests are used for energy it is the result of timber operations that involve residue collection and, to a lesser extent, private harvesting of cordwood that may be permitted as part of stand thinning and debris clearing,

The Forest Service interprets the Multiple Use Act as mandating what may be called “dominant use” zoning. That is, while multiple use applies to an entire forest, particular management areas may emphasize one or another of the uses. In practice this means that for each area, such as a Ranger District, the manager identifies dominant uses and limits others to the extent that they are compatible with the dominant ones. For example, if a particular zone is especially valuable as a wild turkey habitat, constraints will be placed on other uses so that they do not interfere with wild turkey nesting and management. Clearly, this approach to land management has important implications for wood harvesting on Federal lands.

A second key Forest Service policy is that of seeking to assure a “sustained yield” of renewable resources from national forests and rangelands, Sustained yield has been interpreted as “even flow” or “nondeclining yield, ” meaning that the allowable timber harvest on national forests is limited to a yield no higher than can be sustained in perpetuity.

Sustained yield management has been the subject of considerable controversy, largely because on the western national forests that contain large areas of even-aged, old-growth timber, such management often means delaying timber harvests for a long period and, thus, continued low net growth. This can result in greater wood decay and may sacrifice potential growth on land with mature trees. Merchantable timber on private lands has become scarcer as these lands have been “mined” by the forest products industry, leading to growing industry pressure on national forest resources. Many environmentalists support the long-term sustained yield policy as a means of limiting this logging and retaining the esthetic and ecological values of old-growth forests. *

The controversy over sustained yield policies is compounded by poor information regarding forest inventories and uncertainty regarding the possible consequences of different timber yield alternatives. Insofar as current policies influence the supply of wood products, especially sawtimber — and it is likely that they do in a minor way—they also affect wood energy,

An additional area of interest is Forest Service policies and practices for timber harvesting. **currently, for example, logging residues are burned or left to decompose— as much as 1.7 Quads,** in energy terms, are disposed of this way each year— rather than collected and used for energy. A decision to harvest some of these for energy would much improve the energy supply equation in the regions involved.

State and private forest management policies are also of central importance for wood

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* See “ Environmental Effects” under ‘Wood” in ch 4

Photo credit USDA —Soil Conservation Service

Much of the forestland in the Eastern United States is privately owned in small lots

energy, particularly in the East where most forestland is owned in small lots by State governments or private individuals or companies. As noted earlier, it is from this area and ownership class that a large proportion of new wood energy resources must come if wood is to make a significantly greater contribution to the Nation's energy supply. The Cooperative Forestry Assistance Act of 1978 is the latest policy directive that addresses the issue of Federal assistance to, and guidance of, State and private forestry. It provides broad authority to the Forest Service to administer research, extension, and assistance programs, and some of these have been initiated. However, the Federal Government has chosen to downplay these activities in the overall allocation of funds, assuming that State and local agencies and the market can best allocate forest resources and determine the level of management on State and private lands. *

Finally, forest management is affected by policies designed to protect the public health and welfare and the environment. In general, environmental controls implemented by the Forest Service have been initiated by courts that strictly interpreted the mandates of national forest legislation. For example, the Organic Act of 1897 provides that "no national forest shall be administered, except to improve and protect the forest within the boundaries"

* State forestry policies vary widely in character and effectiveness While there are some exceptions, most State programs place a heavy emphasis on forest fire prevention and are able to do only minimal stand management on private land Some States, including Indiana and New York, heavily restrict cutting of wood for any purpose on State lands These limit access to State forests by those seeking to harvest even residues for energy purposes

or for purposes of watershed management. The courts have construed the basic policy behind this language to be regard for the future welfare,[3] and, accordingly, have prohibited practices that would decrease forest growth or water supplies.

In response to these judicial mandates for environmental protection, Forest Service management practices have changed significantly in the last 10 to **20** years. These changes have been accelerated by legislative directives such as the National Environmental Policy Act of 1969 (NE PA, described in detail in the section on "Alcohol Fuels"). Environmental impact statements (EISs) required by NE PA will play an increasingly important role in forest management as demand for wood increases.

At the State and local level, environmental controls on forestry vary widely. Some States have statutes modeled after NE PA that can be used to control the effects of logging on State lands. Other States have varying degrees of forest protection built into the legislation for administering State forests. In many other States, however, the primary impetus to proper forest management on State and private land is section **208** of the Clean Water Act. However, as discussed under "Alcohol Fuels, " section 208 only applies to nonpoint source water pollution and not to land quality or other issues, and its implementation has been delayed due to political, administrative, and other problems.

Energy Policy

DOE has the primary responsibility for research, development, and demonstration in the field of bioconversion, and its Biomass Energy Systems (B ES) Program has launched a number of small projects aimed at wood energy development. Current activities include support for the design of safe and efficient wood heaters, research on silvicultural energy plantations (tree farms), and a *very* modest demonstration of one kind of wood gasifier. The administration of bioenergy development, however, has been deficient in a number of respects. The BES Program has been understaffed and underfunded, and coordination with other agencies, especially in USDA, has been poor, delayed, or nonexistent. Not surprisingly, there also has been a rapid turnover in management.

Recently the biomass program has been restructured and granted some additional technical staff — the BE S Program now numbers five professionals and may increase to eight in the near future — and a wood resource manager has been appointed in the Industrial Applications Program (of the Solar Applications Office) and charged with promoting the rapid commercialization of systems using direct wood combustion. In the future, DOE intends to delegate many wood-related responsibilities to the regional Solar Energy Centers, while retaining overall program guidance in Washington. To improve coordination of biomass and wood energy activities, USDA and DOE currently are working on a memorandum of understanding to clarify the roles and responsibilities of the respective agencies involved.

Although these activities attest to the awakening interest in wood in DOE, it is clear from funding decisions that program activities concerning wood retain a very low priority in the overall Federal energy effort. As indicated earlier, this reflects, on the one hand, the administration's bias in favor of large-scale, centralized applications, especially those that hold the prospect of producing synthetic liquid fuels, and, on the other hand, the belief that wood energy is "ready" and requires little additional support in comparison to many of the other possible candidates for support.

[3]U S v *Shannon*, 151 F 863 (C (' Mont 1907)

Policy Options

There are a number of ways by which the Government might encourage and regulate use of wood energy in the United States (table 19). Indeed, a combination of policy support and high energy prices probably will be required if the contribution of wood energy is to grow

Table 19.—Policy Options: Wood Energy

Action	Objective
• Higher priority for wood energy in Government, especially DOE and USDA	• Increase attention, funding, and interagency cooperation
• R&D: Timber-harvesting technology and demonstration	• Wood fuel-supply system improvement
• R&D: Close-coupled, intermediate-Btu gasifier	• Low-cost retrofit for use of wood (and crop residues) in commercial and industrial sector outside forest products industry
• R&D: Development of oxygen-blown gasifiers designed to maximize yields of gas suitable for methanol synthesis	• Improve methanol synthesis
• R&D: Development of tree hybrids designed to give high yields	• Improve yields
• R&D: Basic research into thermochemistry of biomass	• Develop new, and improve old, fuel options for wood and other biomass
• R&D: Long-term effects on forest soils of short rotation-high biomass removal management	• Protect long-term forest productivity and forest ecosystems
• Programs and incentives to encourage or require good forest management, including assistance in selecting trees for harvest and in the timing of harvests	• Sustain and increase the resource base; make residue available for fuel; prevent environmental damage
• Resource inventories and monitoring	• Establish basis for decision regarding conversion to wood; monitor impact of increased use of wood for energy
• Government steps to make available supplies of wood, especially residues from national forests, and concentration yards	• Increase use of wood; increase reliability of supply
• Direct and indirect support for private wood harvesting activities and establishment of concentrate ion yards	• Establish wood supply system
• Information disseminate ion	• Encourage considerate ion of wood as an option
• Publication of test data on equipment	• Increase understanding and confidence in decisions
• Rapid decision on regulation and emission standards	• Decrease uncertain y
• Extend guarantees against retroactive requirements mandating new expenditures	• Decrease uncertain y
• Encourage utility cooperation in cogeneration	• Use of “excess” residues in forest products industry
• Measures to cushion against very high capital cost of wood-combustion equipment; e.g., loan guarantees, accelerated depreciation	• Rapid adoption of wood-burning equipment
• Special provisions for fuel switching in case of industries now using oil or gas	• Increase fuel-stream flexibility; decrease uncertain y
• Technical assistance systems for prospective users	• Assist in decisions about resources and technologies
• Performance standards for wood stoves and fireplace inserts and other small-scale combustion systems	• Protect user health and safety and control air pollution

SOURCE. Off Ice of Technology Assessment

beyond the 4- to 5.5-Quad/yr level that might otherwise be achieved. In the pages that follow, some of the options available for promoting wood energy growth beyond this level are reviewed.

New Priorities in Administration and Research

As previously pointed out, wood energy has a very low priority in the Government agencies whose policies will affect its growth. If the use of wood energy is to expand beyond the minimum levels OTA has identified, the Federal Government, in particular DOE and USDA-— especially the Forest Service, the Soil Conservation Service (SC S), and the Science and Education Administration — as well as the States must give it much stronger administrative and budgetary support. In addition, there should be less emphasis on large-scale, isolated systems such as tree farms, and more on smaller, integrated arrangements in which energy is not the sole product. This is true of most bioenergy systems-–biogas production can be part of a dairy operation, ethanol distillery byproducts can be fed to animals. Wood is no exception. **Broadly speaking, these new priorities in research and administration are a precondition to the successful implementation of most of the specific initiatives listed below.**

Although one of the attractive characteris-tics of wood energy is that combustion technologies of various kinds are already in use and widely understood, a number of areas remain in which R&D can make an important contribution. Five areas, in particular, still require this kind of support: 1) wood-harvesting technology and demonstration, **2)** wood gasification technology and demonstration, 3) basic research on the thermochemistry of biomass, 4) development of fast-growing, high-yield plant hybrids as fuel sources, and 5) research on the conversion of wood and lignocellulosic materials to ethanol. Specialized timber harvesting for wood energy is new to most energy users, and experimentation with different harvesting strategies and with machines that can harvest timber efficiently and safely in different kinds of terrain and at greater distances from roads, is needed. Also, harvesting programs to demonstrate the costs and benefits of different patterns of wood collection would provide useful information, especially to those contemplating large-scale conversion alternatives.

Perhaps the most important single technical contribution to the expansion of wood energy use would be the development of reliable close-coupled, airblown, intermediate-Btu gasifiers. Described at greater length in volume I I of this report, this technology is critical because it can be used to produce process heat for industry (an option for which direct combustion is not suited), and would al low many current users of oil and gas to convert to wood at about two-thirds the cost of a new wood boiler, while retaining the flexibility to switch back to oil or gas if necessary. This might make wood energy attractive to a broad range of investors whose businesses are located close to wood resources but who are reluctant to commit themselves at high cost to an uncertain source of supply. Although working gasifiers have been built in the past, they need further development to meet the needs of potential users for commercial purposes.

Research on the thermochemistry of wood, also treated in volume II of the report, is needed for possible technical improvement across the whole range of biomass combustion and gasification technologies, as well as fuel and chemical synthesis.

The Resource Base: Establishing a Secure Fuel Supply While Protecting the Forests

One of the principal obstacles to wood energy outside the forest products industry is the absence of an established wood fuel supply and delivery infrastructure. The adoption of new energy technology is often contingent on the investor's sense of confidence regarding long-term reliability of supply at predictable costs. Such confidence is unwarranted in most parts of the United States today.

The Government might take a number of steps to improve the supply outlook. To begin with, **improved inventories of wood resources are needed in most areas. As the demand for biomass grows, it becomes increasingly important to be able to assess total wood inventory and wood growth with** more precision than is possible today. The Forest Service Survey should be redesigned to provide a census of forest inventory and forest growth by species and qualities on a whole-stem biomass basis not obscured by arbitrary assumptions concerning forest use standards and thresholds of commerciality. In addition, it would appear advisable for the Government to: 1) improve the census of forest product use to include wood used for industrial, commercial, and residential fuel; 2) improve the specification, classification, and census of wood residues, including silvicultural, harvesting, and manufacturing residues; and, 3) carefully explore the theoretical feasibility of multiple use forest management that includes fuel as one of the management objectives.

In those regions where the Federal and State governments are major owners and managers of forests, the management agencies might further encourage the establishment of a fuel supply industry by actions such as providing program funds to support the establishment of concentration yards. In the case of utilities and large institutional energy consumers, the Government might make available a guaranteed supply of fuelwood from publicly owned forest material, logging slash, and the woody residues of site preparation, fire prevention, and stand improvement measures. National forest

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decisions regarding the supply of wood can be expected to affect the overall wood market, and policies must be designed with this in mind. **In particular, it is important that the Forest Service assess its current and future timber sales procedures to determine possible impacts of pricing policies on the market for wood energy and on incentives for forest management in the private sector.**

Public forests, because of their size and the ability of management to make discrete inventories and plans, offer excellent opportunities in all regions of the United States to design and implement fuelwood use and forest growth pilot projects that can be evaluated for wider private sector adoption. Finally, there are many incentives that might be adopted to support commercial wood supply systems in the private nonindustrial forestlands. Direct and indirect help in financing timber harvesting (or the purchase of mechanized harvesting equipment), or incentives for forest-thinning activities with the provision that the wood residues be used for energy and the harvest plan be approved by qualified experts, are but two examples. Also worth considering are **educational programs to improve** logger efficiency in conducting integrated harvest operations. Experience in New England has shown that one of the most significant factors in determining the economic viability of harvesting low-quality material with mechanized equipment is the skill of the logging foreman in planning and executing the cut. One way to approach this is the staging of demonstration harvests to provide loggers with an opportunity to see well-executed operations and to show landowners the variety of possible management strategies for their forests.

The options described above would help to establish a reliable wood fuel supply infrastructure. In doing so, however, it is critically important that the protection and improvement of the forest resource be assured. Increased demand for wood energy **might** lead to more intensive and effective forest management that actually would increase the quality and quantity of timber resources. Unfortunately, it is by no means clear that such management will occur automatically, or in a uniform manner, everywhere in the country. A key uncertainty here is the unpredictable behavior of the 4.5 million private, nonindustrial woodlot owners who control 58 percent of the forestland and whose resources will be vital to wood energy supplies. Most of these individuals lack the expertise to make environmentally sound forest management decisions, and it is unclear how they will respond to increasing incentives to manage their lands for wood fuel.

Moreover, economic incentives do not always favor sound forest management. Although the absence of such management may damage forest productivity, landowners must have extremely long planning horizons in order to consider this damage when short-term economic pressures often favor cutting on vulnerable lands or with environmentally damaging techniques.

Other factors that will affect proper forest management include weak regulatory incentives, the often short leadtimes for selecting a logging site and harvesting techniques, the large number of relatively small sites that will make careful implementation, monitoring, and enforcement difficult, and the nature of the potential environmental damage, which does not lend itself to relatively simple technological controls or process changes.

There are a number of avenues available for environmental control in forest management. These include both preventive measures that are implemented before any impacts can occur and mitigative controls that alter the ecosystem response to impacts. *

On national forest lands, the existing policies described above might be expanded to encompass intensive resource management for energy. **The primary legislative change that might be considered is including fuel as one of the statutory forest uses under the Multiple Use Act.** This would remove any potential obstacles to including wood energy supplies in other forest management directives and regulations, including those that implement NE PA. However, the degree to which Forest Service practices conform to existing directives is unclear. Additionally, even though sound management tech-

*See "Resource Base" in vol II

niques may be included in an EIS filed under NEPA, there is no assurance that the specified techniques will be followed.

Forest management practices on State and private lands are more difficult to control at the Federal level. Where these activities are part of a comprehensive Federal program (e. g., incentives for wood energy use) management plans could be made a precondition of participation, and an EIS could be required for the entire program. However, just as management decisions on national forests often are made on a site-specific basis in accordance with general guidelines, techniques for controlling environmental impacts on non-Federal forestland also need to be tailored to a specific site.

In addition, federally mandated controls would be most effective if they were implemented throughout the forestry system rather than only on lands supplying wood for energy. That is, incentives that are tied only to fuelwood would be difficult to enforce without continuous supervision of logging because it would be nearly impossible to prove what wood came from which land once it had been cut. In addition, if the environmental sensitivity of the land is the only variable (and not the kind or quality of timber), forest landowners would just shift their wood fuel activities to less sensitive lands.

At the State and local level, environmental controls could be implemented through logging permit schemes tied to forest management plans. Such schemes might include federally assisted education and demonstration programs. Again, these controls would be easier to implement and enforce if they apply to all forestland.

Finally, as discussed above, vigorous State and local implementation of section 208 of the Clean Water Act could be a powerful tool in controlling nonpoint source pollution from logging, but due to a variety of factors it is unlikely that this will occur.

Energy Conversion: Managing Uncertainty

Assuming that policies designed to protect and enlarge the resource base and to encourage the harvesting, transport, and marketing of fuelwood are adopted, a number of obstacles remain that prevent potential users from converting to wood energy. In many cases, removal of these requires only minor adjustment in policy or program emphasis. One such obstacle, for example, is the lack of public information concerning technologies and their applications. Another is continuing uncertainty about future Government regulations related to health, safety, air quality, and similar issues. **A continued expansion of Government information dissemination activities, along with the preparation and distribution of accurate and understandable environmental monitoring and equipment test data, plus rapid setting of regulatory standards would be helpful in dispelling some of this uncertainty. In the residential heating sector, for example, there** is a need for accurate information regarding the safety, efficiency, and proper installation and operation of wood stoves and fireplace inserts, and for clear guidance regarding emission standards. Although wood stoves are already economical in many parts of the country, the provision of an investment tax credit for this equipment, as well as for wood furnaces, would speed the expansion of wood use in home heating.

For those forest products firms with excess energy resources (i. e., with more residues than needed for onsite power), cogeneration to produce electricity as well as steam may be an economically attractive alternative. Unfortunately, cogeneration often is impeded by utility pricing policies in which backup energy is sold at very high prices, while energy from sources such as cogenerators is purchased at very low prices. Although this problem is addressed in the National Energy Act of 1978, it will take a long time to change rate structures and more regulatory support for cogeneration is needed.

In the commercial/industrial sectors, the high capital cost of wood combustion equipment is a barrier that can be addressed by the provision of tax credits–some already have been authorized, but are not widely used-–loan guarantees, and accelerated depreciation allowances. Wood-fired systems generally require three to four times the capital of comparable oil-fired systems. It would appear that small- and medium-sized businesses, especially, would be able to benefit greatly from such incentives.

Still another problem for businesses considering adding large-scale wood-fueled gasifiers to an oil- or gas-fired boiler is the possibility that, as a result of fuel-switching regulations of the National Energy Act, switching back might be prohibited. If this is the case, turning to wood could decrease fuel stream flexibility and increase uncertainty.

Most prospective wood energy users outside the forest products industry also would benefit from a carefully designed program of technical assistance. Such a program would provide basic information and help those interested work their way through the many complicated steps involved in a decision to convert to wood. This might include assistance with a review of the technology, an assessment of resource inventories, an investigation of applicable Federal and State subsidies and incentives, and perhaps even help with the preparation of engineering plans. Forgivable loans to small- and medium-sized businesses as well as to small utilities for conversion studies also would be of assistance. These loans might be repaid from investment funds if a decision is made to go ahead, and be forgiven if the project should prove unfeasible.

Finally, wood combustion can be an important source of local air pollution. The regulatory structure of the Clean Air Act in regard to stationary sources is described in "Alcohol Fuels." However, most wood-fired equipment will be too small to be affected by Clean Air Act requirements and legislative or regulatory action to reduce emissions may be required as more homes and businesses turn to wood fuel. The easiest option to implement would be New Source Performance Standards for small wood combustion equipment. However, this option overlooks the substantial number of combustion facilities already in place. **In addition, regardless of how emission limits are implemented,** they will be difficult to monitor and enforce due to the great number of dispersed sources.

What impact would these policies have if adopted? The answer is unclear because the uncertainty about key aspects of the wood energy system simply is too great. OTA is confident about the estimate that 4 to 5.5 Quads/yr of energy from wood will be used annually by 2000, but this represents mainly a projection of current trends. If the forest products firms continue to grow and move toward energy self-sufficiency, as much as 4.5 Quads/yr are likely to be derived from wood in that sector. OTA also is confident that the resource base, with proper management, is large enough to sustain energy production in the 6- to 10-Quad/yr range by 2000 or sooner. But **important uncertainties remain, and it is critical that these be acknowledged and incorporated in policy decisions affecting wood.**

Only one technical question appears to be crucial at this point: whether a reliable gasifier can be developed and marketed in the near future. Other technical innovations may help speed the use of wood for energy, but do not appear as important in capturing an entirely new set of users for this resource. The reason is that gasifiers can be used for process heat and give fuel-switching flexibility that is essential in the absence of certainty regarding future wood supplies. In addition, gasification would require less initial investment than direct combustion. Clearly, therefore, this represents a bottleneck that should be addressed as quickly as possible if a greater use of wood energy is desired. The nontechnical uncertainties are more difficult because they have to do mainly with the behavior of diverse groups of producers and consumers and with the operation of complex, multi sector markets.

Perhaps the most important uncertainty concerns the crosspoint between wood consumption and forest depletion. Growth in dependence on wood for energy will mean drawing heavily on the *283* million acres of forests now in the hands of many small- and medium-sized woodlot owners, but very little is known about their management objectives, about how they might respond to incentives to manage their land, harvest wood, and so forth. Currently large proportions of wood used for fuel in residences are cut with little or no professional guidance. Although it may seem economically sensible from a long-term perspective for these owners to manage their resources carefully, it is entirely possible that growth in demand for wood fuel and a desire to maximize short-term profits will lead to regional or local deforestation as well as an overall decline in the quality of national forest resources. For this reason, and because an increase in the resource base should, if at all possible, parallel the growth of wood energy use, policies to enlarge Government support for forest management activities would appear prudent despite the uncertainties listed here. Programs with this objective can always be phased out if private initiatives appear adequate, whereas a lack of adequate forest management would decrease the energy potential obtained from wood and could cause significant environmental damage.

If the forests are more intensively managed, the overall character of these lands will change. Extensive management would alter the physical appearance of woodlands and transform the mix of wildlife supportable by forest ecosystems. To a degree, it is possible to grasp these changes by observing the character of woodlands in parts of Europe where intensive forest management has been practiced for many years.

Finally, there remains a broad range of market uncertainty that stems from the possibility of changes in the prices of petroleum and natural gas and from continuing competition with nonenergy uses of wood and land. It is quite possible, for example, that as larger amounts of wood are cut, the nonenergy uses for incremental wood supplies may grow more attractive economically, resulting in far less conversion to wood energy than might otherwise be expected. Because feedstock costs are such an important part of biomass energy system costs, the continuing possibility that wood prices may rise will tend to dampen enthusiasm for this energy source outside the forest products industry.

To summarize, all these uncertainties make it difficult to predict with any precision or confidence either how much energy will be produced from wood with the adoption of even vigorous promotional policies or the full consequences of the success of such policies for the environment and nonenergy wood markets, This conclusion, in turn, suggests several important principles that should be considered in the formulation of wood energy policies. First, **legislators should acknowledge the uncertainty about the effectiveness of policy initiatives at the outset by making their commitments tentative and by including in legislation, where appropriate, requirements for subsequent assessment of results.** Sunset provisions, price and quantity thresholds for subsidies and incentives, statutory requirements for review of existing policies, and similar provisions might contribute to this goal. For example, policy makers might require a formal review of the wood energy system, the condition of the forest resource, and the need for continued incentives for conversion to wood when 5 Quads/yr of wood energy are being consumed. Second, the United States should simultaneously monitor with great care the responses to promotional policies and other regulations in order to detect problems and unanticipated impacts. **Continuous monitoring of the condition of the forest resources, the kinds of technologies being deployed, and the environmental and social impacts of wood energy use, is essential.**

As this report has tried to emphasize, the possible problems and costs associated with increasing reliance on forest resources are not as well understood as the benefits. In general, these appear to be manageable but are of the kind that are often neglected until it is too late, The broad tendency in the United States, when the goal is perceived to be that of “commercializing” an economic activity, has often been to piece together a rough package of loosely related incentives and then to assume that the problem has been solved, Wood energy, like all biomass energy systems, requires not a solution but a long-term commitment to the management and guidance of interdependent systems of economic activity. This, in turn demands careful orchestration of incentives, controls, and regulations, along with constant monitoring of the consequences of policy choices.

Alcohol Fuels

Introduction

Biomass has become the object of widespread public and legislative interest because it is the only source of liquid fuels from solar energy produced with available technology. As noted in chapter 4, the largest potential source of alcohol fuels is methanol from wood, grass and legume herbage, and crop residues. If managed properly, these feedstocks can be obtained with a minimum of environmental damage or disruption of existing markets. Ethanol from grain and sugar crops represents a much smaller potential source of liquid fuels. However, ethanol is likely to remain important for at least the next decade as a means of diversifying domestic energy sources and as a transitional fuel until other synfuels become commercial.

A number of technical and policy constraints could limit the commercial production and use of alcohol fuels, and policy support will be needed if these fuels are to make a significant contribution to domestic energy supplies. In the short term, the limiting factors include the long leadtimes for constructing new distilleries and for converting idle capacity, the need to demonstrate conversion technologies using cellulose feedstocks, and the lack of a reliable feedstock supply infrastructure. In the long term, alcohol fuels production could be limited by competition with other synfuels for investment capital and by competition with feed and food. Other issues surrounding ethanol from grain and sugar crops include its net energy balance as well as its potential for environmental damage and for significantly altering the focus of agricultural regulation.

Policy makers might also promote onfarm and other small-scale operations that would contribute to liquid fuel self-sufficiency in agriculture and other sectors. Onfarm distillation may be inhibited in the short term by its cost (especially relative to the subsidies for gasohol sold at the pump), the lack of relatively automatic inexpensive distilling equipment, and farmers' lack of technical knowledge. in addition, onfarm use would mean sacrificing the value of ethanol as an octane booster in gasoline. Once farmer acceptance has been achieved, however, the cost or labor may become secondary to the value of some degree of fuel self-sufficiency.

The policy context for alcohol fuels is very broad, encompassing forestry, agricultural, revenue, energy, and environmental policies. This section analyzes policy considerations related to the production of grain and sugar crops for ethanol and to the conversion and use of all alcohol fuels. Policy related to supplies of wood and grasses and residues is discussed in other sections of this chapter. Because ethanol from grain and sugar crops has attracted such widespread attention, and because it has potentially severe environmental, institutional, and economic consequences, its policy implications are discussed in greater detail than is the case for the other fuel cycles.

Resource Base

Several hundred million gal/yr of ethanol could be produced from sugar and starch crops and food wastes without expanding crop acreage or withdrawing grains from traditional markets. Production beyond this level, however, would require cultivating additional acreage or diverting supplies from traditional domestic and international markets. Unless feedstock supplies are managed carefully, grain-based ethanol might disrupt the complex and highly regulated agricultural economy and could result in environmental degradation. To some extent, these problems can be avoided in the market or under current agricultural and environmental policies. In some instances, however, new policies will be necessary.

Current Agricultural Policy

Since the 1700's, American farmers have been dissatisfied with the prices of agricultural commodities that result from free competitive market conditions. After World War 1, farm prices and income were low, and farmers began to turn to the Federal Government for price supports and controls on surpluses. During the 1920's, Congress twice passed legislation designed to subsidize grain exports, but President Coolidge vetoed it both times because he believed foreign nations would take retaliatory steps.[4]

In 1929, under President Hoover, the Federal Farm Board was established to administer a program of "orderly marketing" based on storing surplus grain that was depressing grain prices. Although the grain was stored, the program failed, partly because grain supplies remained uncontrolled and partly because the anticipated increase in demand did not materialize due to the depression.[5] In 1933, the Federal Farm Board was replaced by the New Deal production control, price support, and storage programs. This basic regulatory structure, with the addition of export subsidies, continues today in order to balance the supply and demand of agricultural commodities, maintain farm income, and ensure reasonable prices for consumers.

The present form of these programs was established under the Food and Agriculture Act of 1977 (Public Law 95-1 13), one of the most comprehensive pieces of farm legislation ever passed by Congress. Under this Act USDA estimates the acreage required to meet domestic, export, and inventory needs for a crop year. This "national program acreage" is then divided by the estimated national acreage harvested for each basic commodity (corn, cotton, peanuts, rice, tobacco, and wheat) in order to arrive at an allocation factor that is used to determine individual farm program acreage. Since early in 1980, the national program acreage allocation has included projected demand for alcohol fuel feedstocks. Farmers who agree to limit their production to the allotted acreage are eligible for a variety of economic programs including price supports, loans, and other payments. The production control and income support programs are described below in order to establish the policy context within which ethanol feedstock production must be integrated.

Production Controls

If ethanol production is to be increased by bringing additional acreage under intensive cultivation, the acreage most likely to be used first is the land under production controls. The USDA programs designed to control production by enforcing the individual farm acreage allotments include set-aside lands, diverted cropland, and the cropland adjustment program.

The set-aside approach was initiated under the Agricultural Act of 1970 (Public Law 91-524), which required farmers to remove a percentage of their acreage from production and devote it to approved conservation uses in order to be eligible for other farm support pro**grams, including loans and other payments. Farm operators must meet the set-aside requirements for all crops ("cross compliance"). Thus, if farmers grow both wheat and feed grains, they must participate** in both set-aside programs to receive benefits from either. Farm operators who agree to reduce their acreage by 10 to 20 percent are guaranteed a slightly higher price for their crops than farmers who do not participate in USDA programs. In 1978 there were 13.3 million acres in the set-aside program, but the amount of set-aside acreage varies annually.

Farm operators also may divert other lands to approved conservation uses in return for additional payments under several USDA programs. In years when the demand for a basic commodity (such as wheat or feed grains) is projected to be relatively low, or when reserves are high, farmers may voluntarily divert acreage to conservation uses in return for diversion payments. Approximately 5 million acres were under cropland diversion in 1978; again, the acreage varies annually.

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4 S Barber, et al, *The Potential 01 Producing Energy From Agriculture*, contractor report to OTA, May 1979

[5]Marion Clawson, *Policy Directions for U S Agriculture* (Baltimore, Md The Johns Hopkins Press, 1968)

As mentioned above, agricultural policy requires set-aside and diverted lands to be converted to "approved conservation uses." In practice, there is a wide range of such uses; some would conflict with ethanol feedstock production while others specifically provide for it. In general, set-aside and diverted acreage must be devoted to crops or practices (such as grasses and legumes, small grains, trees or shrubs, terraces and sod waterways, and water storage) that will protect the land from wind and water erosion. Both set-aside acreage and diverted lands also may be devoted to wildlife food plots or habitat or to public recreation in accordance with standards developed by USDA in consultation with other agencies. Government assistance often is available to help defray the costs of these activities.

Moreover, under the Emergency Agricultural Act of 1978 (Public Law 95-279), USDA may permit all or any part of the set-aside or diverted acreage to be used to produce any commodity (other than the commodities for which acreage is being set-aside or diverted) for alcohol fuel feedstocks. This energy use of diverted and set-aside lands is permitted under the Act if USDA determines that the production is desirable in order to provide an adequate supply of liquid fuels and is not likely to interfere with the other goals of farm programs. Participating farmers would continue to receive set-aside payments for these lands. During years in which there is no set-aside or acreage diversion requirement, the Act authorizes USDA to formu late and administer a program for the production of commodities for liquid fuels. Under such a program, producers of wheat, feed grains, upland cotton, and rice would receive incentive payments to devote a portion of their acreage to energy crops. The amount of these payments would be determined by the degree of participation necessary to ensure an adequate supply of commodities for liquid fuels. However, this program has not been implemented by USDA.

The third production control is the cropland adjustment program. It was authorized by the Food and Agriculture Act of 1965 to reduce the costs of farm programs; to assist farmers in converting their land to nonagricultural uses to promote the development and conservation of soil, water, forest, wildlife, and recreation resources; and to establish, protect, and conserve open spaces and natural beauty. Under the cropland adjustment program, farm operators entered into 5- to 10-year contracts to maintain conservation practices on land taken out of production. I n issuing these contracts, USDA gave priority to practices most likely to result in permanent conversion of the land to nonagricultural uses. I n 1976, 1.2 million acres remained under cropland adjustment program contracts.

Income Support Programs*

Many proponents of gasohol argue that it would increase commodity prices and thus farm income, and therefore would be a boon for farmers. In order to assess this argument, it is necessary to understand USDA programs related to basic commodity prices (corn, cotton, peanuts, rice, tobacco, and wheat). The agricultural programs designed to protect farm income and consumer interests are price supports, direct income and deficiency payments, loans, and disaster payments.

A target price is used as the basis for providing farmers with direct income payments that vary inversely with the market price. Target prices are determined annually from USDA estimates of production costs (excluding land) and of returns to management. When the average market price received by farmers during the first 5 months of the marketing year is less than the target price, eligible farmers receive deficiency payments based either on the difference between the two prices or the difference between the target price and the support price, which is determined by the loan rate at which farmers can borrow on their crop production. In practice, the loan rate becomes a price floor below which the market price is unlikely to fall, because the Government loan effectively eliminates financial pressure on the farmer to sell at any price.

To obtain a USDA nonrecourse loan, the farm operator pledges a specified amount of

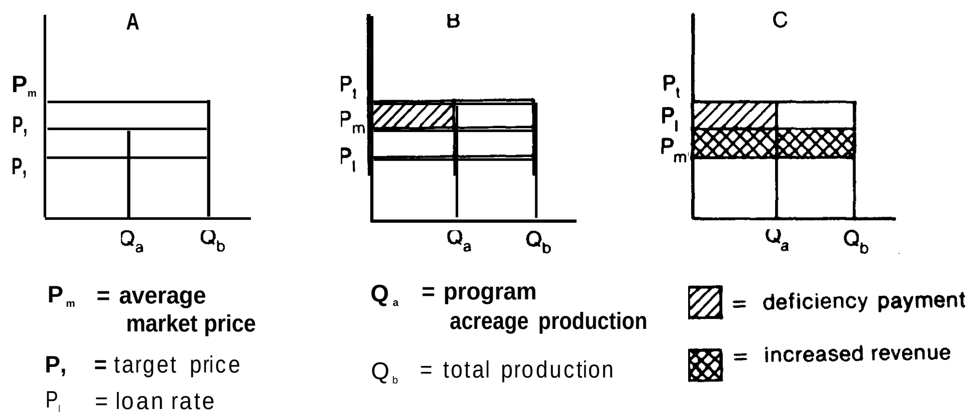
*Much of the discussion in this section is from S Barber, et al , Op cit his crop as collateral. The amount of the loan is equal to the loan rate (or support price) times the quantity of crop pledged. At the end of the loan period (9 to 12 months) the farmer may either repay the loan with interest or forfeit the stored crop. Farmers may extend a nonrecourse loan and receive a prepaid storage payment by signing a 3-year contract to enter the farmer-held reserve program. Under this program, the farmer agrees to hold the crop for the contract period or until the market price reaches the release level (140 percent of the loan rate for wheat and 125 percent of the loan rate for corn). The farmer only pays interest during the first year of the contract at 7 percent. Farmers can release the grain earlier by paying a penalty.

Finally, payments are available when natural disasters either prevent normal planting operations for basic commodities or result in a harvest of less than 60 percent of normal production. The disaster payment rate is 50 percent of the target price for the deficit of production below 60 percent of normal.

Operation of the current farm price and income program under three circumstances is illustrated in figure **37.** In part A, the market price is above both the target price and the loan rate. In this situation, farmers would sell their crops in the market, no loans would be requested, and no deficiency payments would be made. In part B, the market price is below the target price but above the loan rate. Under these circumstances, producers would not elect to take the nonrecourse loan but would receive a deficiency payment equal to the difference between the target price and the market price times the production from program acreage. In part C, the market price is below both the target price and the loan rate. In this situation, farmers probably would take advantage of the nonrecourse loan program, which would increase their crop revenue, and they would receive an additional deficiency payment on their program acreage equal to the difference between the target price and the loan rate times the program acreage.

The current farm programs have two main effects. First, the deficiency payments represent an income transfer from the general public to farmers; they have little effect on market prices. Second, the loan program operates as a price support that tends to increase prices to consumers up to the level of the loan rates and transfers income from consumers to farmers. Thus, the current program splits the incidence of income transfer between consumer payments (if the market price is below the loan

Figure 37.—Operation of the Current Farm Program



SOURCE S Barber, et al *The Potential of Producing Energy from Agriculture* contractor report to OTA May 1979 rate) and general tax revenues (for deficiency payments).

Reserves and Exports

Agricultural policy also provides for storage and export of commodities— both potential sources of alcohol fuel feedstocks. Strategic reserves are maintained as part of the general agricultural programs. The sources of reserves include farmer-held reserves and production in excess of farm marketing quotas for basic commodities. As discussed above, farmer-held reserves are stored under contract and released for sale on the market at a specified time. Under the market quota programs for basic commodities, when production exceeds the farm allotment the farmer stores the excess and uses it the next year to offset the farm allotment for that year, or the Commodity Credit Corporation (CCC) may acquire the excess as part of its strategic reserve. [n general, the reserves are used in disaster relief and welfare assistance or as a hedge against future supply deficits.

Agricultural policy also encourages the expansion of international trade to use the abundant U.S. agricultural productivity to aid the balance of payments. **In 1978, for example, agriculture had a favorable trade balance of $13 billion. Moreover, concessionary commodity exports are subsidized by the Federal Government to provide assistance to developing countries.**

Research, Education, and Extension

In addition to the regulatory programs discussed above, USDA also sponsors research, education, and extension service programs that could affect the production of energy commodities.

The Agricultural Research Service supports basic and applied research in a number of areas including plant sciences, entomology, soil and water conservation, and agricultural engineering. The Cooperative State Research Service (CSRS) administers congressionally mandated research in the State Agricultural Experiment Stations. Several of the research programs sponsored by these agencies could affect bioenergy, including research in crop productivity, and processing, storage, and distribution efficiency. CSRS also administers special grants to develop solar technologies that can be used in modern farm operations.

The Agricultural Extension Service and SCS inform farmers of the results of agricultural research. The Extension Service, through the land grant colleges, gives instruction in agriculture and related subjects and encourages use of the information by people not attending the colleges through demonstrations, publications, and direct farm visits. **In addition, the Extension Service conducts** a model farms program that includes demonstrations of the effective use of solar energy in agricultural operations. SCS works with county Soil and Water Conservation Districts (SWCDs), watershed groups, and Federal and State agencies with related responsibilities to bring about physical adjustments in land use that will conserve soil and water resources and protect long-term agricultural productivity.

Finally, the Economics, Statistics, and Cooperatives Service performs studies to support cooperative groups that market farm products, purchase production supplies, etc. Technical assistance is available to farmers on organizing new cooperatives, improving cooperative performance and efficiency, and related business services.

Agricultural Policy Options

As already indicated, if the United States decides to aggressively promote ethanol from grain and sugar crops as a means of increasing domestic energy supplies, distillery demand for feedstocks must be integrated into the agricultural economy without subverting the goals of the existing policies described above (table 20). There are three main sources of distillery feedstock supplies (see ch. 4): diverting commodities from export or other markets to distilleries, bringing currently idle and potential cropland into production, and changing the mix of crops currently grown and reformulating animal feed. Each of these supplies can be provided either by modifying agricultural policies or by maintaining current policy

Table 20.—Policy Options: Alcohol Fuels

Action	Objective
• Include alcohol fuel feedstock demand in USDA national program acreage allocation	• Expand feedstock supplies; integrate feedstock supply into agricultural production system
• Divert limited quantities of feedstocks from export, feed, and other markets	• Expand feedstock supplies; protect commodity prices
• Direct or indirect support for domestic sugar crops used as alcohol fuel feed stocks	• Expand regional feedstock supplies; support domestic sugar producers
• Direct or indirect support for new cropland planted in alcohol fuel feedstocks	• Expand feedstock supplies; increase farm income
• Strengthen support for onfarm and cooperative storage	• Maintain the ability to moderate short-term supply deficits for all grain consumers
• Monitor grain ethanol production and grain prices and re-evaluate incentives as distillery capacity increases	• Determine correlation between grain ethanol and inflation in food prices; protect consumer prices
• Provide production tax credits for all alcohol fuels	• Equalize tax treatment between ethanol and methanol and between private and commercial production; stimulate alcohol fuel use
• Implement section 208 of the Clean Water Act	• Control agricultural non point source pollution; protect long-term agricultural productivity
• Expand farm information, education, and support programs on soil conservation	• Reduce soil erosion; protect long-term agricultural productivity
• Require approved conservation plans for all cultivated lands	• Reduce soil erosion; protect long-term agricultural productivity
• Program support for alcohol fuels used as octane-boosting additives in gasoline	• Increase displacement of premium fuels
• Simplify BATF regulations for alcohol fuel producers	• Reduce cost of alcohol fuels; encourage production
• Use gasoline tax revenues to support new alcohol fuels production capacity	• Encourage gasoline conservation; increase alcohol fuels supplies
• Direct and indirect support for onfarm and cooperative alcohol fuel production	• Increase agricultural and rural liquid fuel self-sufficiency
• Support distilleries that convert from grain to cellulosic feed stocks	• Reduce potential for food-fuel competition
• Limit number of BATF permits for grain ethanol production	• Reduce potential for food-fuel competition
• Extend auto warranties to include methanol-gasoline blends and straight alcohol fuels	• Reduce consumer risks; encourage alcohol fuel use
• Provide long-term gasoline supply guarantees to alcohol fuel-gasoline blenders	• Increase alcohol fuel use
• Provide long-term supply guarantees for auto fleets	• Increase alcohol fuel use; provide controlled situation for studying fuel effects on autos and emissions
• Require grain ethanol distilleries to use coal, biomass, solar, or other non premium boiler fuels	• Maximize premium fuel displacement
• Study liquid fuels system vis-a-vis methanol	• Determine most economic strategies for using methanol to displace oil
• R&D; Develop high-yield crops that do well on land poorly suited to food crops	• Increase feedstock supplies; reduce potential for food-fuel competition
• R&D: cellulose-to-ethanol	• Expand alcohol fuel supplies; reduce potential for food-fuel competition
• R&D: Develop inexpensive, safe, highly automated small-scale stills, including the capability to produce dry ethanol and dry distillers' grain, and to use a wide range of feedstocks	• Decrease the cost and increase the use of alcohol fuels on farm; increase agricultural and rural liquid fuel self-sufficiency
• R&D: demonstrate herbage-to-methanol processes	• Expand alcohol fuels supplies; reduce potential for food-fuel competition

SOURCE Off Ice of Technology Assessment

and using end-use subsidies such as the Federal excise tax exemption to modify market forces in agriculture. Both options are discussed below. A subsequent section outlines market and regulatory options for controlling the environmental impacts that could result from the production of grain ethanol. The reader should keep in mind that **maintaining long-term stability and productivity in agriculture will require an integrated approach that combines agricultural, energy, and environmental policy initiatives.**

If current production of grain and sugar crops for feed were diverted to distilleries, it would yield substantial quantities of ethanol (up to 30 billion gal/yr, more than half of it from corn). Although it is highly unlikely that this much grain ethanol would be produced at the expense of traditional agricultural products, OTA's analysis indicates that as much as 1 billion to 2 billion gal/yr could be produced without significantly inflating food prices.

Part of this 1 billion to 2 billion gal/yr would come from the diversion of commodities from export markets. This could be done either by USDA or through other political diversions such as the recent Soviet grain embargo, or could result from distillers outbidding exporters. The former would make it easier to control the amount of grain diverted. The latter would be limited by how much distillers can afford to pay for feedstocks in order to remain in operation. Given the profitability of producing fuel ethanol with current subsidies, the latter market limit may be high, and before it is reached, the price of grain feedstuffs in export markets could increase—or grain exports decrease — substantially.

Reducing commodity exports or increasing their price in order to augment U.S. energy supplies could result in adverse responses from importing countries. Furthermore, the resulting reduction in oil imports would not necessarily represent a net gain in the balance of trade if commodity exports also are reduced. That is, there is a relative economic advantage in exporting $2.50/bu corn and importing oil until the price of oil reaches $40 to $45/bbl.

An alternative source of feedstocks for grain ethanol would result from farmers substituting one crop for another and reformulating animal feed. Again, crop switching could be accomplished within the framework of the existing national program acreage allocation or could occur in response to higher prices for distillery feedstocks. The primary constraints on crop switching are limits on the degree to which animal feed can be reformulated and still retain its nutritive value, and the amount of cropland that is suitable for switching to corn or other ethanol feedstock cultivation.

Finally, it has been suggested that sugar crops could be used for fuel ethanol feedstocks. Although total domestic sugar production would yield only about 800 mill ion gal/yr of ethanol at a significantly higher cost than ethanol from corn, the United States is the world's largest raw sugar importer and the domestic industry currently is depressed due to rising land, labor, and other expenses. The Department of Labor estimates that 4,500 sugar workers have been laid off in the past 3 years,[6] while the General Accounting Office reports that substantial defaults on Government loans to domestic sugar producers are occurring as a result of low-cost sugar imports.[7] The domestic price of sugar is higher than the world price due to import tariffs and other price supports designed to protect domestic producers.[8]

Either imported or domestic raw sugar could be diverted to ethanol production. One option for using imported sugar would be to allow ethanol producers to purchase raw sugar on the world market (i.e., without import tariffs). However, this probably would allow the world market price to rise to match the U.S. price and would increase the price of other products containing sugar. Also, there would be a net increase in the U.S. balance-of-trade deficit.

Alternatively, domestic sugar sold for ethanol production could be subsidized, allowing the growers to recover their costs but providing distillers a guaranteed cheap feedstock. Due to the physical limits on sugar crop production in the United States and to the probable cost of the ethanol, this option is not likely to produce substantial quantities of liquid fuel. It might, however, attract interest in sugar-producing areas as a means of increasing regional alcohol fuel production and further diversifying domestic liquid fuels supplies.

The third major source of distillery feedstocks is cultivation of potential and currently idle cropland. As discussed above, approximately 18.3 million acres were under production controls in 1978 (but the amount varies from year to year). In addition, a 1977 SCS survey of private lands classified 40 million

[6] *Employment and Earnings* (Washington, D C Department of Labor, Bureau of Labor Statistics), monthly

[7] *Questionable Payments and Loan Defaults in Sugar Programs* (Washington, D C General Accounting Office, Mar 16, 1979)

[8] *Reduction in the U.S Import fee on Sugar* (Washington, D C General Accounting Office, July 17, 1979)

acres as having a high potential for being converted to cropland and another 95 million acres as having medium potential.[9]

Any program designed to increase agricultural production for ethanol feedstocks must consider several factors. First, the available uncultivated lands are subject to problems usually not associated with normal cropland, such as high erosive potential, existing land uses, limited size, and drainage, seepage, and flooding, that will increase annual variability in yields and the potential for environmental damage. **Because of the increased probability of reduced yields or crop failures, incentives for ethanol could include a storage reserve equivalent to a 6-month or greater supply of feedstocks to provide a buffer against short-term supply deficits. This** reserve could be implemented through either agricultural programs or distillery subsidies. Finally, if the demand for food and the conversion of cropland to other uses continues to increase, the quantity of land potentially available for energy crop *production* will decrease. Therefore, programs designed to promote grain ethanol should either be reversible or be able to accommodate a change in ethanol feedstocks (e. g., to cellulosic feedstocks), and policymakers should consider ways to preserve agricultural land uses.

[9] *1977 National Erosion Inventory* (Washington, D C U S Department of Agriculture, Soil Conservation Service)

Given these considerations, two principal options for increasing agricultural production to supply ethanol feedstocks are discussed: 1) expansion of current agriculture programs to include energy crops, and 2) elimination of existing production controls. For these options, the potential impacts on commodity production and prices and on Government expenditures have been projected through computer modeling and the results are presented to facilitate comparison between these options and

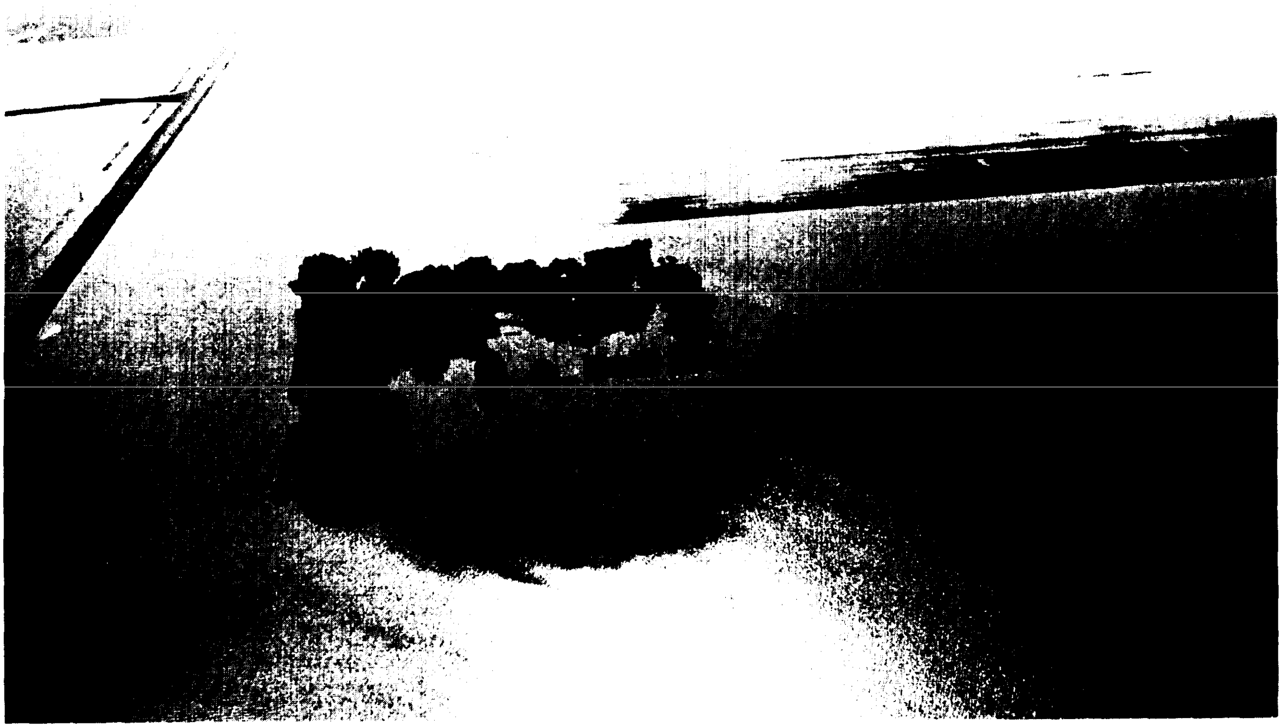


Photo credit. USDA, Cal Olson

Problems such as flooding potential increase the annual variability of crop yields current agricultural trends.'" The reader should keep in mind that these modeling results are **not** predictions, but projections of hypothetical situations based on assumed values for particular variables (see app. B for description of model). The real future values of those variables may be very different and other factors not built into the models could produce radical changes. Note also that the model shows only the hypothetical effects of increased **corn** production; other ethanol crops could have different impacts.

The first option incorporates the exogenous demand for grain for ethanol production within the context of the current commodity programs. The deficiency payment, nonrecourse loan, and domestic grain reserve programs continue to operate as described above, but set-aside acreage may be used to produce grain for ethanol. Ethanol feedstock crops would be purchased by CCC and sold to distilleries as needed. In this option, the higher market prices created by distillery demand (stimulated through either conversion process or end-use subsidies) would be the primary incentive for using set-aside and other idle lands for ethanol crops.

The second option would eliminate production control and deficiency payment programs, but increase the loan rates to nearly the level of target prices. This would result in a production incentive and level of farm income protection roughly equivalent to those provided by current agricultural programs. The increased loan rates also would provide the means to increase CCC inventories of corn for sale to distillers.

The modeling results for these options are shown in table 21 to compare two means of implementing policies designed to stimulate increased production of corn for use as an ethanol feedstock as well to compare various levels of corn production. In the long run, there are few operational differences between the two options because, by 1985, the first evolves to closely approximate the second. That is, over time in the first option the set-aside acreage diminishes. Hence, the loan rate becomes the primary means of ensuring the stability of farm income under both options. In effect, the increased demand for corn obviates the need for pure income support (deficiency payments), and the price support provides price stability.

As shown in table 21, either of these options results in substantial impacts on the agricultural system at ethanol production levels of 4 billion gal/yr. Season average corn prices increase 30 percent while the annual instability in corn prices nearly doubles. In addition, strategic reserves are reduced by 55 percent. Together, these effects undermine two of the goals of agricultural policy: to maintain stability in commodity prices in order to protect farm income and consumer prices, and to maintain strategic reserves in order to moderate short-term supply deficits.

Furthermore, several features of these options may prove to be unacceptable even at the l-billion- to 2-billion-gal/yr level of ethanol production. The first are the economic impacts related to commodity prices and Government program expenditures. Even at the 2-billion-gal level, the exogenous demand results in increased corn prices that probably would increase the price of food to consumers. Under the first option, Government expenditures for CCC operations, acreage diversion payments, and farmer-held reserve payments also increase. As discussed in the review of income support programs, consumers would bear most of these costs. The composition of the expenditures also changes significantly because the deficiency payments are substantially above those projected for the existing agricultural programs; these payments reflect the cost and risk in cultivating new lands and represent an income transfer from the general public through tax revenues. They have little effect on market prices. As the supply commitment level increases, these costs diminish because of higher corn prices, but are more than offset by increasing net purchase costs of CCC. Under the second option, deficiency and diversion payments are eliminated, but CCC purchase costs again increase steadily with the level of supply commitment, and again, must

'['Ronald L Meek hof, et al , U S. *Agricultural Policy and Gasohol Simulation of Some Policy Alternatives,* June 1979

Table 21.—Potential Impacts of Increased Corn Production for Gasohol

	Current agri-cultural trends	First option 1 x 10⁹ gal/yr	First option 2 x 10⁹ gal/yr	First option 4 x 10⁹ gal/yr	Second option 1 x 10⁹ gal/yr	Second option 2 x 10⁹ gal/yr	Second option 4 x 10⁹ gal/yr	Percent difference between options 1 x 10⁹ gal/yr	Percent difference between options 2 x 10⁹ gal/yr	Percent difference between options 4 x 10⁹ gal/yr
Corn prices ($/bu).	$2.53	$2.53	$2.67	$3.21	$2.56	$2.70	$3.32	– 1.2	– 1.1	– 3.4
Soybean prices ($/bu)	$7.00	$6.95	$6.90	$7,34	$6.66	$6.52	$6.38	4.4	5.7	1.4
Corn production (10^6 bu)	7,250	7,467	7,590	7,730	7,569	7,588	7,580	– 1.4	—	2.0
Soybean production (10^6 bu)	2,188	2,125	2,088	NA	2,192	2,170	NA	– 3.1	– 3.9	–
Corn exports (10^6 bu) .	2,056	2,055	1,996	1,850	2,115	1,957	1,783	– 2.9	2.0	3.7
Soybean exports (10^6 bu)	932	936	953	945	975	1,005	1,047	– 4.1	– 5.3	– 10.2
Corn reserves (10^6 bu)	1,960	1,561	1,242	NA	2.146	1,554	NA	–31 .6	– 22.3	–
Value of corn production and deficiency payments (10^9 $).	$18.6	$19.7	$20.9	NA	$19.3	$20.4	NA	2.1	2.4	—
Value of soybean production (10' $).	$15.0	14.5	14.1	NA	14.4	13.9	NA	0.7	1.4	—
Government expenditures (10' $)	$1,626	1,915	1,834	NA	1,635	1,586	NA	15.8	14.5	—

NA = not available

[a]Positive difference indicates first option is greater relative to second option, negative difference indicates second option is greater relative to 's'option

SOURCE Ronald L Meekhof et al *U S Agricultural Policy and Gasohol Simulation of Some Policy Alternatives*, June 1979

either be subsidized (i. e., paid by taxpayers) or borne by consumers.

Second, there is the shift that could occur in soybean production at or beyond 1 billion to 2 billion gal/yr of ethanol. On the supply side, some farmers would shift their acreage from soybeans to corn in response to the increased price of corn, while on the demand side, the substitution of distillers' grain for soybean meal reduces the demand for soybeans. (Note that the distillers' grain also may be substituted for feed grains — such as corn — that have been diverted to ethanol production; in this case the demand for soybean meal would not be reduced so much.) At the same time, under the second option, soybean prices decrease significantly and consequently the export demand increases. Soybean meal producers have substantial capital investments they would want protected from the distillers' grain competition, yet the meal could not be exported in large quantities due to competition with foreign production.

Finally, despite the higher payments for farmer-held reserves under the first option, corn in storage is reduced by approximately 20 percent at 1 billion gal/yr and 37 percent at 2 billion. Decreased reserves mean that the ability to moderate supply fluctuations due to variations in yields would be reduced, and the likelihood that distillery feedstocks would be diverted to feed markets in bad crop years would increase.

Relatively minor market adjustments or changes in implementation of current agricultural policies could, to an extent, resolve some of these issues. For example, increased Government expenditures would be moderated if CCC did not function as the middleman between producers and distillers. Instead, distillers could purchase their own cropland or negotiate long-term supply contracts with farmers as a hedge against feedstock supply interruptions. Both these alternatives, however, tend to favor consolidated ownership of large blocks of cropland, to the detriment of small farmers. Moreover, **it is likely that storage and reserve policies will have to be changed anyway in order to maintain the ability to moderate short-term supply deficits for all grain consumers.**

Despite the potential problems with ethanol production at the l-billion- to 2-billion-gal/yr level, the difference in their magnitude relative to *4* billion gal/yr is important. That is, these results indicate that lower levels of production can be achieved for a very low resource cost. Basically, idle agricultural land can be used at little cost and the current subsidies that keep land idle can be transferred to a subsidy for converting grain to ethanol. Thus, it probably is not necessary to modify agricultural policy as in the second option. Rather, current agricultural policies in conjunction with the market forces created by end-use subsidies such as the gasohol excise tax exemptions (see "Conversion and End Use,") can be used to increase distilleries' share of grain supplies. At a minimum, this will reduce the need for farm income supports and it could change the focus of agricultural subsidies to maintaining reserves as a hedge against food price inflation in years with low crop yields, and to controlling agriculture's environmental problems and the conversion of cropland to nonagricultural uses.

Assuming the gradual phasing out of present farm commodity price supports as distillery demand drives prices up above the levels needed to maintain farm income, the central policy issues will become the size of the gasohol tax exemptions, how long they should remain in effect, and whether they should be replaced by other incentives or subsidies. These issues are discussed in detail under "Conversion and End Use."

In the long run, if the demand for food and the conversion of cropland to other uses continue to increase, the land available for energy crops will dwindle, and, in the absence of significant changes in consumer behavior, market intervention may be necessary to prevent inflation in commodity prices. Alternatively, distilleries could be required to shift to cellulose feedstocks. Policy issues related to feedstock conversion also are discussed under "Conversion and End Use. "

Environmental Controls

Agriculture often degrades land quality and pollutes surface and ground waters; the two problems are closely linked. For example, erosion reduces land productivity and is the major cause of sedimentation in surface waters. Similarly, fertilizers and pesticides build up in the soil and alter its ecology and then enter aquatic ecosystems through agricultural runoff. As discussed above, USDA production controls require the use of "approved conservation practices" on idle agricultural land in order to control wind and water erosion as well as insects, weeds, and other pests. These practices are designed and implemented on set-aside lands by SCS through local SWCDs, and are subsidized by Federal and State cost-sharing funds. In addition, SCS and the Extension Service provide technical assistance to farmers who request aid in developing a soil conservation plan for their entire farm, but implementation of the plan is voluntary.

The surface water sedimentation that results from erosion and the water pollution that can result from "runoff containing pesticides, fertilizers, and other chemicals are regulated under the Clean Water Act of 1977 (formerly the Federal Water Pollution Control Act of 1972), which requires States to develop plans for the control of water pollution from nonpoint sources. This approach, based on areawide waste treatment plans, was inaugurated in the 1972 Act and reaffirmed and strengthened under the 1977 Act.

In general, under section 208 of the Clean Water Act, the Environmental Protection Agency (EPA) establishes guidelines for the identification of areas with substantial water quality control problems. Local agencies, with State and Federal assistance, then develop areawide waste treatment management plans for the problem areas. The local agency also must implement a continuing areawide waste treatment management planning process that includes identification of agricultural sources of water pollution and procedures and methods (including land use requirements) to control nonpoint source pollution to the extent possible. Section 208 is implemented through best management practices (BMPs), which are determined to be the most effective and practicable (including technological, economic, and institutional considerations) means of preventing or reducing nonpoint source pollution to a level compatible with water quality goals.

A variety of problems, including the political sensitivity surrounding any Federal involvement in land use planning, a lack of direction in EPA guidelines for determining the degree and type of nonpoint source pollution to control, and short deadlines for developing novel and controversial land use management techniques, prevented effective implementation of section *208* following its passage in 1972. * Consequently, more immediate and better understood water pollution problems with strict statutory control deadlines, such as sewage treatment and industrial process controls, received funding priority over section 208, even though 208 was intended to provide integrated planning and management for all pollution sources.

In the intervening years, knowledge about nonpoint sources and their control has improved vastly, and the 1977 amendments reflect this knowledge in the revisions to section *208.* These amendments include a USDA-administered program to enter into 5- to 10-year contracts with rural land operators to install and maintain BMPs under plans approved by a soil conservation district and consistent with the areawide plan. In return, the land operator receives technical assistance and up to 50-percent cost sharing. This program marks a radical departure from the traditional approach to nonpoint source control in that the plan is implemented by a Federal, rather than a State or local agency, while the cost-sharing contract represents a direct Federal subsidy for land management practices that will reduce nonpoint source pollution.

In the future, EPA implementation of section 208 will tend to focus more on regulatory, statewide nonpoint source controls. The 1977 criteria for evaluating nonpoint source programs reinforce the trend toward regulatory control by allowing permits, licenses, and contracts (as well as voluntary management techniques) to be required when justified by the intensity, scope, and type of nonpoint source pollution as well as by landownership patterns and other physical factors. Nonregulatory controls will be allowed only when they can achieve water quality standards. In addition, EPA is developing a 4- to 6-year plan that will emphasize statewide nonpoint source control; in 1978, EPA and USDA began a joint program to demonstrate the effectiveness of statewide BMP coordination in seven model States.

Nevertheless, given farmers' resistance to regulatory controls, the low priority assigned to agriculture's environmental problems by State and Federal agencies, and other constraints on nonpoint source control (see discussion in ch. *4),* it is unclear whether future implementation of section *208* will be any more effective than it has been in the past. Thus, **if set-aside and other diverted cropland or potential croplands are used to produce grain for ethanol, the water pollution effects could be substantial. In general, these lands have a higher erosive potential than land presently under production and therefore** are more likely to contribute to sedimentation of surface waters. In addition, set-aside and other lands may not be as productive, requiring increased use of fertilizers and pesticides[11] that contribute to chemical water pollution. Finally, these lands may be tied up in competing land uses.

Because of the potential for environmental damage and because it usually is not economical in the short term for individual farmers to protect against such damage, the Government may want to consider introducing additional incentives for environmental controls. These incentives could be implemented within the current policy context or new environmental control policies could be developed. These options include both voluntary and mandatory controls.[12]

The policies discussed below share several common considerations. First, any policy that applies only to energy crops will be difficult to implement because farmers could shift those crops to their least sensitive lands. Thus, **if envi-**

• See also " Environmental I mpacts'' in the ''I ntroduction " to Ch 4

" For policies related to the use of pesticides, see *Pest Management Strategies in Crop Protection* (Washington, D C Off Ice of Technology Assessment, October 1979), OTA-F-98

1 'Much of the following discussion on nonpoint source control options is from D L Uchtmann and W D Seitz, "Options for Controlling Non-Point Source Water Pollution A legal Perspective, " *Natural Resources Journal* 19587, July1979

ronmental control policies are to have more than a minimal effect, they should be introduced throughout the agricultural system.

Second, the farming community is more likely to accept policies if traditional agricultural agencies implement them than if new agencies are created or existing nonagricultural agencies are involved. The traditional agricultural agencies may, however, have to shift to an advocacy role to which they are unaccustomed. Moreover, using traditional agencies would involve the least implementation cost.

Third, the farming community views policies that allow flexibility in selecting the means of control as more rational and more equitable than policies that impose uniform practices or prohibitions. Of course, when farmers consider controls to be commercial or profitable, they are more likely to adopt them voluntarily. When controls represent a net loss in farm income, or when the only perceived benefits are environmental, mandatory programs or prohibitions may be necessary.

Fourth, the environmental effects of agriculture are extremely difficult to monitor. Consequently policies that result in changed farming practices or that impose limits on the use of chemicals will be easier to implement and enforce than those that penalize farmers for polluting.

Finally, any controls that limit the availability of farmland (e. g., green belts along streambanks) also will affect the supply of feedstocks for ethanol production, and ultimately will contribute to inflation to the extent that the limits on production are not offset by environmental benefits.

Voluntary programs that could be used to control the environmental impacts of intensive agriculture include educational programs and economic incentives such as low-interest loans, and cost sharing and tax policies.

The current SCS, local SWCD, and Agricultural Extension Service education programs rely primarily on public meetings and demonstration projects. These programs could be expanded to use other communication methods, such as print and broadcast media, mass mailings, and more frequent direct farm visits. The initial goal of such an expansion would be simply to increase farmer recognition of environmental issues; surveys reveal that few farmers are aware that agricultural practices have significant environmental impacts,

In general, agricultural education programs have a long tradition of Federal and State support and would not be difficult to implement. The primary consideration here is whether education programs alone would be sufficient to encourage farmers to adopt conservation practices that may mean less intensive farming (and in some cases forgone income) or capital outlays for equipment. Therefore, this option probably would be more effective when combined with other voluntary economic incentives, such as loans, cost sharing or tax credits, or with mandatory programs.

Low-interest loans could be offered for farm investment in equipment or practices that would reduce the environmental impacts of intensive agriculture. The relative advantage of these loans would be determined by the prevailing market interest rate. However, during recessions or other periods of “stagflation,” such legislatively mandated loans could contradict executive branch policies designed to limit credit. Additionally, during recessions or in poor crop years defaults could be a problem unless the loans were coupled with deficiency payments. Finally, the amount available under this option would be limited to legislative appropriations.

Current cost-sharing programs to encourage soil conservation on set-aside and other production control lands could be expanded to cover any agricultural environmental controls. Qualifying expenditures might include measures such as the construction of terraces or the implementation of alternative pest management strategies, with the Government providing up to 50 percent of the farmers’ costs. If the farm operator fails to maintain the measures for which the subsidy was granted, the subsidy would be revoked and/or a monetary penalty imposed. As with low-interest loans, cost-sharing programs ultimately are limited by the legislative appropriation.

Tax incentives such as credits and exemptions also could be offered for environmental controls. Current tax law already allows a deduction for certain soil and water conservation costs that otherwise would be nondeductible capital expenditures. However, a deduction alone probably would not be sufficient to achieve more than isolated controls, and a tax credit equal to a set percentage of the cost of any environmental controls could be instituted. In effect, such a credit would be a cost-sharing policy implemented through the tax system, and not limited by legislative appropriations. The credit could be limited to a percentage of the actual outlays for equipment and practices or could also include any lost income that might result from less intensive management, but the latter would be more difficult **to calculate and verify.**

At the State level, tax incentives also might include exemptions from excise and sales taxes for any equipment needed to implement nonpoint source controls, as well as special property tax provisions for lands on which environmental controls are maintained.

Mandatory environmental controls for cropland under intensive cultivation include approved conservation plans and economic penalties. It should be emphasized at the outset that, while mandatory nonpoint source controls ultimately may be necessary, it will be extremely difficult to get farmers to accept them. In addition, mandatory controls must be phased in with great care in order to avoid damage to farm productivity and income.

As discussed above, SCS and SWCDs provide technical assistance to those farmers who request aid in developing a soil conservation plan for their farms. In addition, these agencies approve mandatory conservation uses for set-aside and other production control lands. These mandatory uses could, to some extent, be carried over to other croplands, or new mandatory conservation plans could be developed. Such plans could be implemented through the general agricultural programs or could be included in a mandatory contract system under the 1977 amendments to section 208 of the Clean Water Act. Under either system, the approved conservation plan would include a full range of environmental controls based on numerical standards such as soil-loss tolerance limits.

Approved conservation plans also must take into account the competing uses of the land to be developed. For example, some diverted croplands have been "permanently" converted to nonagricultural uses such as wildlife habitat and recreation, windbreaks or shelterbelts, permanent cover and timber, or water impoundments. In many cases, these uses should not be disturbed.

Environmental control plans should be developed at the farm level to accommodate regional differences and to provide farmers enough flexibility to choose from the full range of available controls. Guidelines could be provided at the Federal or State level for various combinations of terrains, weather and climate, soil types, crops, and other variables.

Mandatory economic incentives include taxes or charges for the absence of environmental controls. For example, erosion or effluent charges might be based on the absence of soil-conserving farming methods, on soil-loss tolerance limits, or on allowable levels of sediments and chemical pollutants in the runoff from agricultural land. As discussed above, the effluents are difficult to measure; changes in farming practices would be easier to enforce. **Individual farmers** would determine whether it was more cost effective on their farm to pay a charge or tax, and if it were not, which controls they would implement.

A system of charges or taxes based on regulatory effluent limitations also could be set up on a market basis, allowing those farmers whose effluents are below the limits to market the difference to farmers who are unable to meet the limits economically. This scheme would primarily be advantageous at high production levels when all available land is needed for energy crop production but a straight charge system would inhibit the cultivation of particularly sensitive lands. The primary problem with a market scheme is that it only addresses the water quality controls. Where erosion degrades land quality, marketing the rights to do so would seriously threaten productivity. Other problems with a market scheme are the difficulty in measuring effluents and the tendency for sensitive lands to be grouped together, thus subjecting the adjacent ecosystems to disproportionate environmental impacts.

As with the options to increase corn production, modeling results are available for the impacts of some environmental control options'[3] and are presented in table 22. Again, it must be cautioned that these are hypothetical projections based on assumptions about the values of particular variables. They are not predictions.

These model results are important in the short term because they suggest that if environmental controls are imposed on increased corn production for use as ethanol feedstocks, the price of that corn and consequently the price of the ethanol will be higher than generally assumed in the gasohol literature. However, the costs indicated by the model do not include the reduction in social costs from a cleaner, more productive environment. The cumulative economic impact of policies intended to stimulate energy crop production coupled with those to control environmental impacts has yet to be calculated, nor has the impact of mandatory erosion control policies on the net availability of ethanol cropland been quantified.

The model results also suggest that, in the long term, erosion control policies will result in dramatic improvements in the maintenance of soil productivity. But, they indicate that it is not economic for individual farmers to adopt erosion control practices unless they have extremely long planning horizons and assume a very low discount rate on future income.

Finally, the model results have significant implications for equity. For example, sensitive croplands are not evenly distributed geographically. Thus in some areas increased production would be impossible, while in areas with a very low erosive potential farm income could increase substantially. Moreover, policies such as regulatory controls and taxes are more effective than subsidies in improving the degree to which individuals pay for benefits received or are compensated for social costs incurred. Finally, some of the policies tend to reduce the income differences within the population while others tend to widen the gap.

''W D Seitz, et al , *Alternative Policies for Controlling Nonpoint Sources of Water Pollution* (Washington, D C Environmental Protect Ion Agency, April 1978), EPA-600/5-78-005

"See Ibid , for a detailed discussion of the equity implications of nonpoint source controls

Table 22.—Potential Effects of Alternative Erosion Control Policies

	Percent change						Millions of dollars			
Policy	Soil loss	Corn production	Soybean production	Corn prices	Soybean prices	Nitrogen load	Producers' surplus[a]	Consumers' surplus[b]	Government Cost[c]	Net social Cost[d]
2-ton/acre-yr soil loss limit	– 70	- 6	– 15	15	20	- 5	$ 15	-$1,205	–	-$1,190
5 ton/acre-yr soil loss limit	–45	– 2	- 3	4	5	—	231	– 433	–	-202
$0.50/ton/yr soil loss tax	-30	–	—	—	1	—	– 458	160	$212	- 85
$4/ton/yr soil loss tax	- 67	—	—	– 1	6	—	– 1,506	344	772	– 390
$5/acre subsidy for terracing	—	—	—	—	—	—	0.11	028	- 56	– 5
$40/acre subsidy for terracing	-27	—	—	—	—	—	942	- 9	– 1,233	-300
100 lb/acre nitrogen application limit	– 2	– 2	—	4	—	-24	20	– 320	–	-300
100 lb/acre nitrogen application limit combined with 5 ton/acre-yr soil loss limit	–45	- 3	- 3	6	3	– 24	247	-772	–	-525
100 lb/acre nitrogen application limit combined with 2 ton/acre-yr soil loss limit	-74	– 9	-16	17	19	-30	228	– 1,605	—	– 1,377
50 lb/acre nitrogen application limit	-1	-13	– 9	25	11	– 48	2,037	-3,325	–	– 1,288
50 lb/acre nitrogen application limit combined with 5 ton/acre-yr soil loss limit	– 45	-14	– 12	28	14	– 49	2,180	-3,677	–	-1,497
50 lb/acre nitrogen application limit combined with 2 ton/acre-yr soil loss limit	– 74	-20	-23	39	26	– 58	1.674	– 4,163	—	-2,489

[a]Producers' surplus is equivalent to the land rents from production and terracing.
[b]Consumers' surplus is the difference between what consumers are willing to pay and the market Price
[c]Subsidies paid or taxes received Does *not* include cost Of administration.
[d]Sum of the changes in producers' surplus, consumers, surplus, and Government costs. Does *not* include environmental benefits

SOURCE W D Seitz, et al , *Alternative Policies for Controlling Nonpoint Sources 01 Water Pollution* (Washington D C , Environmental Protectlon Agency, April 1978), EPA-600/5-78.005

Conversion and End Use

If alcohol fuels are to make a significant contribution to U.S. energy supplies, incentives may be needed (depending on the price of oil) for the construction of large- and small-scale conversion facilities as wet l as for the use of these fuels in automobile and other engines. Current and proposed policies already provide incentives to increase conversion capacity and alcohol fuel use. Other policies, however, pose constraints to alcohol fuels and should be revised if the Government decides to promote such fuels aggressively. The current policy context for alcohol fuels, as well as policy options to stimulate production and use, are discussed below.

In general, policies intended to stimulate investment in conversion facilities or to encourage the use of alcohol fuels will be the same for ethanol and methanol. That is, the conversion technologies and end uses for these fuels are similar, and for most issues one policy would be sufficient. However, issues applicable only to one of these fuels should be given special attention. For example, ethanol distilleries might be required to use alternative fuels (e. g., coal, biomass, solar) in order to maximize premium fuel displacement, but there is no comparable problem with methanol facilities. Similarly, methanol is more likely to damage rubbers and plastics in automobiles and to increase evaporative emissions; factory warranties—some of which already include ethanol use— could be expanded to cover methanol blends.

As with the options related to the resource base, the policies discussed below share several common considerations. First, both alcohol fuels will displace more premium fuel if used as an octane booster. Higher subsidies to alcohols used as octane-boosting additives would encourage this use. Second, both fuels could affect the drivability of automobiles and could damage some auto parts. Auto warranties ***might*** encompass such problems. Third, variables such as distillery size or ownership can be used by policy makers to influence the degree of sectoral or regional energy self-sufficiency to be achieved. A size "ceiling" or limiting funding to individual or cooperative ownership would emphasize onfarm and other rural operations, while a size "floor" would encourage the construction of commercial-scale distilleries. Finally, long-range energy planning by policy makers should incorporate the need to remove subsidies for conversion facilities and gasohol use as the economics improve or for ethanol if competition with traditional food crops for agricultural land becomes a problem (see below). Such planning also should consider the implications of a possible future shift in feedstock composition as well as those of developing domestic reliance on a liquid fuel whose availability ultimately may be limited.

Tax Policies and Other Subsidies

Ethanol: Policies to Encourage Production

Current U.S. revenue policy regulates the manner in which alcohol is produced and distributed, and taxes both alcohol and liquid fuels.

The Federal Government has taxed the production of alcoholic beverages since 1791; nearly $5.5 billion was collected in 1976. The laws and regulations designed to protect this source of revenue include restrictions on operating conditions, licenses and permits, bond and reporting requirements, and distribution controls. In general, the requirements for an operating permit and license include construction specifications, such as secure premises and sealed distilling systems, and operating conditions, such as constant supervision by the Bureau of Alcohol, Tobacco and Firearms (BAT F), designed to prevent unauthorized diversion of the distilled spirits. In addition, the distillery operator must post a distilled spirits bond to ensure payment of penalties or fines, and must maintain complete and accurate records including details of all distilled materials received, the quantity of alcohol produced and denatured, and final disposition of the denatured spirits. Daily reports of distillery activities are filed with the responsible BATF operator while monthly operational reports are submitted to the Regional Administrator.

All of the above requirements add significantly to the cost of alcohol production, and could discourage investment in distillery capacity. Recognizing this problem, the Energy Tax Act of 1978 (part of the National Energy Act) requires the Treasury Department to recommend legislation that will simplify the regulation of fuel alcohol producers while maintaining the integrity of the beverage alcohol tax system. In addition, the President has directed the executive branch to simplify and reduce Federal reporting requirements for fuel alcohol producers. The primary targets in this process should be the security requirements that increase distillery construction costs, permit and other procedures for the manufacture and use of small-scale stills, and the frequency and level of detail in BATF recordkeeping and reporting provisions. On the other hand, additional production reports could be required by energy agencies to monitor gasohol supplies and use and to facilitate long-range energy planning.

In addition to the regulations on denatured spirits, taxes are levied on gasoline and on special liquid motor fuels at the Federal, State, and local levels. Gasoline is subject to a Federal tax on its sale by any producer. However, the Energy Tax Act of 1978 exempts gasohol from the Federal motor fuel excise tax between January 1, 1979, and October 1, 1984; President Carter supports a DOE recommendation that this exemption be extended beyond 1984. A number of States also have exempted gasohol from State gasoline taxes or have placed an additional tax on gasoline to subsidize construction of fuel alcohol distilleries. As can be seen in table 23, the combined Federal and State tax exemptions represent a substantial ($16.80 to $56.70/bbl of ethanol) subsidy for gasohol.

DOE also has revised the crude oil entitlements program to include ethanol produced from biomass. This provides an incentive equal to about $0.05/gal of ethanol used in gasohol. However, this program expires on September 30, 1981, and the incentive is substantial only for those who begin ethanol production soon.

Table 23.—State Tax Incentives for Gasohol

State	Exemption (in dollars per gallon)	Total subsidy (Federal plus State, in dollars per barrel of ethanol)
Arkansas	$0.095	$56.70
Iowa	0.085	52.50
Indiana	0.08	50.40
Louisiana	0.08	50.40
Montana	0.07	46.20
Oklahoma	0.065	44.10
Colorado	0.05	37.80
Kansas	0.05	37.80
Nebraska	0.05	37.80
New Hampshire	0.05	37.80
North Dakota	0.04	33.60
South Carolina	0.04[a]	33.60
Wyoming	0.04	33.60
South Dakota	0.03	29.40
Connecticut	0.01	21.00
Maryland	0.01	21.00
No State tax exemption		16.80

aReduced to$002 in 1982

SOURCE Off Ice of Technology Assessment

Revenue policy also provides for a IO-percent additional investment tax credit for facilities that convert feedstocks (including coal and biomass) into “synthetic liquid fuels. ” The Internal Revenue Service (IRS) currently is developing regulations to implement this credit, which was included in the Energy Tax Act of 1978. DOE is assisting IRS with technical definitions and interpretations that should ensure that facilities to produce alcohol fuels will qualify for the credit.

Nontax subsidies and other economic incentives available to the emerging gasohol industry include loan guarantees, grants, and low-interest loans as well as marketing regulations. Loan guarantees are available for alcohol production facilities under two programs. Four Government-guaranteed loans of up to $15 million were granted under the Agricultural . Act of 1977 to facilities that convert agricultural products to alcohol. In addition, in May 1979, President Carter announced a series of major initiatives intended to assist small towns and rural areas in approaching energy self-sufficiency, including $11 million in grants, low-interest loans, and loan guarantees for the construction of 100 small-scale plants to produce fuel alcohol. This program is administered by the Economic Development Administration and the Community Services Administration, with DOE providing technical guidelines. Funds became available in fiscal year 1980.

In addition, DOE gasoline-marketing regulations have been revised to allow refiners— as well as resellers and retailers — to sell gasohol as a separate grade of gasoline and to directly pass on the cost of the alcohol. Under previous rules, refiners had to sell gasohol as unleaded regular gasoline and absorb the alcohol fuel cost by averaging their gasohol-refining costs with the costs of all refined products.

New tax incentives for commercial distilleries might include investment or energy production tax credits, accelerated depreciation, and special deductions for the interest paid on construction loans. A special tax on gasoline also could be imposed and the resulting revenue earmarked for distillery construction, including direct subsidies such as low-interest loans and guaranteed prices for feedstocks and for gasoline for blending. Authorization for some of these options exists but would need to be expanded in scope for maximum effect; others would require new legislation. At the State level, distilling equipment and feedstocks could be exempt from any excise and sales taxes. Special property tax classifications for fuel alcohol distilleries also could be developed. In addition, State gasoline tax exemptions could be expanded or special gasoline taxes imposed.

In addition to commercial distribution of alcohol fuels, their production and use on farms and by cooperatives also is likely to be important in diversifying energy supplies. The resource base is closer to rural areas and gasohol use there would involve the least transportation and distribution costs. In addition, energy use in agriculture is structured around critical time "envelopes" (e.g., planting, harvesting) that reduce short-term flexibility or conservation potential and make supply reliability crucial. Even minor energy shortages at critical periods could reduce agricultural production significantly.[15] Onfarm distillation would alleviate this vulnerability. Moreover, onfarm stills are promoted among farmers as a means of reducing grain surpluses and thereby increasing grain prices and, thus, farm income.[16]

Incentives for small-scale stills might include tax deductions or credits for feedstocks and equipment, special income tax provisions for cooperative distillery ownership, or direct subsidies such as cost-sharing and interest-free loan programs. Those that are already available are shown in table 24. All the incentives for onfarm distillation should include information programs and technical assistance; these might be implemented through the Extension Service and the Economics, Statistics, and Cooperatives Service.

Policy makers should consider several factors in promoting onfarm and cooperative use of ethanol. First, using ethanol in diesel engines (e. g., in farm machinery) would negate its value as an octane booster. In addition, only 35 percent of the fuel used in retrofitted diesel engines can be displaced by ethanol; more extensive modifications would be needed to displace a larger proportion of the diesel fuel. On the other hand, only 2 percent of the corn crop from a typical farm would provide 35 percent of the farm's diesel fuel requirements. Onfarm use also is constrained by its cost relative to the subsidized price of gasohol sold at the pump and by the lack of relatively automatic inexpensive distilling equipment, both of which operate against farmers' acceptance of onfarm distillation. The former could be offset by production tax credits for alcohol fuels not sold commercially.

Moreover, ethanol production cooperatives might have their own special benefits and costs. Co-ops would allow a relatively large number of small farmers to benefit from scale economies and could enhance the sense of rural community. However, inequalities among members in large coops may lead to an inequitable internal distribution of benefits. In addition, large co-ops would tend to serve a wider market and may evolve to closely resemble corporate-owned distilleries, thus poten-

[15] Frederick H Buttel, et al , "Energy and Small Farms A Review of Existing Literature and Suggestions Concerning Future Research," report prepared for the Project on a Research Agenda for Small Farms, National Rural Center, Washington, D C , 1979

[16] Iowa Corn Production Board, "Corn Alcohol Farm Fuel ! Things You Need to Know, " 1979

Table 24.—Sources of Public Financing for Small-Scale Ethanol Production

Organization	Program	Applicant eligibility	Type of assistance	Eligible activities	Purpose of project	Limits of project
U S Department of Agriculture/Science & Education Admin	Alcohols & Industrial Hydrocarbons (see 1419 of Food and Agricultural Act of 1977, Public Law 95-1 13)	Colleges and; universities having a demonstrable capacity in food and agricultural research	Grants of 2 to 3 years duration for research	Research on the evaluation, handling, treatment, and conversion of biomass resources for manufacture of ethyl alcohol	To develop improved processes for production of alcohol from biomass	$100,000 per grant of 2 to 3 years duration
U S Department of Agriculture/Science & Education Admin	Energy Research (see 1414 of Food and Agricultural Act of 1977, Public Law 95-1 13)	Colleges and universities having demonstrable capacity in food and agricultural research	Grants of 2 to 3 years duration for research	Research on fermentation and related processes for production of alcohol, other than ethanol, and hydrocarbons	To develop improved methods of production and blending. marketing, and utilization of products	$100,000 per grant of 2 to 3 years duration
U S. Department of Agriculture/Office of Energy	No restrictions	General advice	General advice on USDA program avail. ability	Biomass production for alcohol fuels; conversion and use of alcohol	Serves as information clearinghouse and provides for coordinated USDA programs	None
U S Department of Agriculture/Farmers Home Admin	Business & Industrial (B&I)	Cooperatives, private Investors in town of less than 50,000	Loan guarantees	Fixed costs, operating capital	Creation of jobs, economic growth in communities under 50,000 population	$25,000.000 per Project maximum Priority on small and intermediate scale of $1,000,000 or less
U S Department of Agriculture/Farmers Home Admin	Operating and Farm Ownership Loans	Farmers, farmer cooperatives	Direct loans at cost of borrowing, loan guarantees	Fixed assets, working capital	Improvement of farm income	$200,000 direct loan, $300,000 loan guarantee
U S Department of Agriculture/Farmers Home Admin	Community Facilities	Private nonprofit public entitles	Loans at 5%	**Construct Ion loans, working capital**	Improvement of the levels of public services and economic growth	Same as B&I ($25,000,000 project maximum) priority on small and intermediate scale of $1,000,000 or less
Housing and Urban Development (HUD)	Urban Development Act Ion Grant	Distressed cities and urban counties	Grant to city to be used for public improvements or loans to developer	Fixed assets related expenses	Stimulate employ. ment and tax base in distressed cities	None
Small Business Administration	Small Business Energy Loan Act, Public Law 95-313	Small business, including farmers and cooperatives for solar and energy conservation technologies	Loans and loan guarantees	Working capital, research and supplies, plant construction, materials, development, manufacturing equipment for alcohol fuels purposes	Promote small businesses in alcohol production-related activities	Direct loans of less than $350,000, loan guarantees of less than $500,000, no more than 30% for R&D, no more than 35% for working capital
Department of Commerce/Economic Development Administration	Public Works and Development Facilities	States. local governments, Indian tribes, non.profit organizations	Grants for 50 to 80% of a total project cost depending on need	Construction and equipment of alcohol fuel plants, priorities on small. scale plants (less than 1 million gal/yr)	To stabilize or stimulate local economy, agricultural area em. phasis	Generally $300.000 per project Must be EDA Designated redevelopment Area
Department of Commerce/Economic Development Administration	Business Development Assistance	Business enterprises including cooperatives	Direct loans up to 65%; loan guarantees up to 90%	Fixed asset and/or working capital for production plants or auxiliary facilities to such plants	Help job situation, Increase crop markets, Increase supply of transportation fuel	Generally for $500,000 minimum size Plants must be in eligible areas This program nor really would not be appropriate for individual farmers
Community Services Administration	Currently funded by CSA Rural and Small Farm Energy Grantees	Grant (limited)—technical assistance	Construction and operation of demonstration plants serving energy needs of rural low-income residents, provision of technical assistance to other communities in small alcohol production	To develop and disseminate efficient technologies for small-scale fuel alcohol production	Grants go only to 5 currently funded CSA projects Phase II technical assistance available to other eligible organizations	

Table 24.—Sources of Public Financing for Small-Scale Ethanol Production—continued

Organization	Program	Applicant eligibility	Type of assistance	Eligible activities	Purpose of prefect	Limits of project
Department of Energy	Biomass Energy Systems Program	Individuals, farmers, businesses institutions (no restrictions)	Technical assistance competitive awards	Conversion of biomass to alcohol fuels	R&D for onfarm systerns advanced energy crops collection and harvesting improvements, and advanced conversion technologies	None
Department of Energy	Small Scale Technology Program	Individuals and small Institutions	Grants	Small-scale renewable energy sources	Develop Innovative small-scale renewable energy technologies	$50,000 per project over 2 years
Department of Energy	Alternative Fuels Utilization Program	Individuals, farmers, businesses Institutions (no restrictions)	Competitive awards	R&D—also testing of alternative fuels	Develop and test alternative fuels including alcohols in diesel and Internal combustion engines	None
Department of Energy	Urban Waste Programs	Individuals, businesses, institutions, communities (no restrictions)	Competitive awards—loan guarantees are under consideration	Conversion of urban and municipal waste products to energy	Conduct R&D and demonstrative techniques converting municipal waste to gases and liquids energy	None
Department of Energy	Office of Consumer Affairs	No restrictions	Technical, economic, and regulatory advice	Small-scale onfarm alcohol production systems	Disseminate state-of-the-art information — train the public in small alcohol fuels facilities	None

SOURCE:Department of Energy *Fuel From Farms,* February 1980

tially negating many of the benefits to the farming community. On the other hand, even small co-ops may not have the financial means to take advantage of economies of scale, and they may be subject to the problems of the members' unwillingness to participate actively.[17]

Ethanol: Policies to Limit Production

All the subsidies and incentives discussed above make it extremely profitable to produce ethanol for use as an octane-boosting additive in gasoline. In the short term, these subsidies may be justified because they make investments in new ethanol capacity more attractive and thus increase the rate at which new capacity becomes available. Arguments can be made for ethanol distillation as one of the synfuel technologies that can be used immediately as a hedge against the rising price of imported oil and against the effects of another oil import interruption.

As noted above, these conversion and end-use subsidies for grain ethanol are likely to become more important than agricultural programs in determining distillers' share of commodity markets. If this in fact occurs, the form, magnitude, and duration of the subsidies become critical issues.

First, the form of the subsidy will determine its effect on the indirect cost of ethanol production. For example, State gasohol excise and sales tax exemptions could reduce available highway funds, while a special tax on gasoline could provide revenue to subsidize the expansion of distillery capacity, spread the cost among gasoline users, and encourage conservation. On the other hand, such a special tax would provide a more direct link between ethanol production and food price increases.

Second, when the available subsidies are added up they can be quite large. The $0.04 Federal excise tax exemption alone adds at least $1/bu to the purchasing power of gasohol users relative to food consumers or livestock feeders. State tax exemptions often add at least an additional dollar to fuel users' relative purchasing power. Furthermore, many of the ethanol conversion and end-use subsidies that have been proposed or are in place have no expiration date. Yet, the need for subsidies could be obviated by increased distillery capacity re-

[17] Michael Schaaf, *Cooperatives* (Washington, D.C.: Exploratory Project for Economic Alternatives, 1977).

solving economic questions about grain ethanol production, by increases in the price of oil, or by increases in the price of or demand for food requiring that distilleries switch feedstocks.

Consequently, DOE and USDA should monitor the economic and other effects of grain ethanol production carefully and reevaluate the need for incentives as planned capacity approaches 2 billion gal/yr, and then set new production limits for further reevaluation, if appropriate. Policy incentives for ethanol also could be made self-limiting with sunset provisions, price or quantity thresholds, or similar requirements.

If adverse economic effects do occur, and policies are not self-limiting, three principal options could be used to arrest the growth of grain ethanol production. First, policy makers could remove grain ethanol subsidies. If the price of oil is so high that ethanol production continues to grow without subsidies, taxes on fuel ethanol use could be instituted. Of the three options, a tax system would represent the least market interference.

Second, policy makers might require distilleries to switch from grain to cellulosic feedstocks. Because commercial cellulose-to-ethanol processes are not yet well defined, it is uncertain exactly what process changes would be necessary. But, based on current knowledge, conversion to cellulosic feedstocks could cost nearly as much as the initial investment in the grain-based distillery. Moreover, administering mandatory conversions would be more expensive than a tax system, and the taxes might achieve the same goal through market forces.

Third, policy makers could limit permits for new grain-based distilleries. Although this option implies a high degree of market interference, it would allow subsidies and other incentives for grain ethanol production to remain in place up to a specified capacity (e. g., 2 billion gal/yr) while retaining control over the industry's growth. Moreover, some gasohol proponents maintain that cellulose-to-ethanol conversion processes will be developed successfully before grain-based ethanol causes major food price increases. If this development in fact occurs, limits on grain ethanol distillery permits would not limit the overall growth of alcohol fuels. Again, however, most of these objectives could be accomplished through a tax system and its effects on the market.

Methanol

Many of the above policies for ethanol also apply to methanol. The major difference between the two fuels is that methanol could be produced in much larger quantities, either from biomass or coal, at relatively low costs. Also, there are unresolved technical questions about the use of methanol-gasoline blends. Therefore, policies should be designed to encourage the use of methanol both as a stand-alone fuel and in blends. The more attractive options include using methanol in gas turbines for peakload generation (currently fueled with light distillate oil), in appropriately modified automobiles in captive fleets (11.7 percent of the automobiles and light-duty trucks in 1976[18]), and in diesel engines modified for dual-fuel use. The first two options increase gasoline supplies while the third increases the availability of diesel fuel.

Subsidies can reduce the cost of the methanol used for fuel, while tax credits or grants could be made available for converting existing equipment to methanol or applied to the added cost of new equipment capable of using methanol. The diesel engine option is particularly attractive because: 1) diesel fuel usage may increase sharply in the 1980's due to an increased number of diesel passenger cars, 2) the methanol will reduce visible particulate emissions, 3) the diesel engines can continue to operate normally if methanol supplies are unavailable, and 4) a methanol distribution system eventually would enable noncaptive fleet automobiles to use pure methanol. With incentives for using methanol in blends and as a standalone fuel, the market could choose the more appropriate options. The introduction of gasoline pumps with the capacity to blend different amounts and kinds of alcohol, and even to dispense pure alcohol, also would help introduce these fuels.

[18] *Transportation Energy conservation Handbook* (2d ed, Oak Ridge National Laboratory, October 1977), OR NL-5493

Energy Policies

in addition to subsidization, gasohol production and use could be encouraged through both supply and market guarantees. DOE already has the authority to provide supply guarantees to gasohol manufacturers by ordering oil companies to provide them with gasoline for blending into gasohol. For maximum effect, DOE could mandate long-term supply contracts between oil companies and distillers of all sizes. **In addition, DOE could be author**ized to allocate fuel ethanol to areas experiencing gasoline shortages.

The principal market guarantee options are fleet use, mandated levels of use, and purchase guarantees. Fleet use would be applicable mainly to Government-owned vehicles, such as motor pools, police, and other public service cars, or to large private operations such as rental car agencies, taxicabs, and delivery trucks, and could involve mandated long-term contracts for gasohol supplies. Fleet use would have the advantage of providing somewhat control led circumstances for evaluating gasohol performance and emissions. Mandated levels of use (i. e., requiring that all automotive fuel sold be at least X percent alcohol) should be limited to areas with abundant feedstocks. Negotiated purchase guarantees would virtually eliminate any marketing uncertainties for the fuel producer.

Finally, Federal and State Governments should consider rewriting their regulations (where necessary) to give equal weight to ethanol and methanol, and to provide for blends that contain less than 10 percent alcohol fuels. In addition, R&D funding is needed to determine the best ways of introducing methanol into domestic liquid fuel supplies from fuel production and distribution to the various end uses. The results of such a study would enable policies to be directed toward promoting methanol fuel use.

Environmental Policy

For the most part, the regulatory structures to control the environmental impacts of commercial gasohol production and use are in place. These include the environmental reporting requirements established under NE PA, the Clean Water Act regulations on point source discharges, and the Clean Air Act requirements for stationary sources. In addition, the use of ethanol as an automobile fuel is affected by Clean Air Act provisions related to mobile source emissions.

NEPA is designed to ensure that Federal agency decision making considers environmental amenities and values along with the traditional economic and technical factors. As part of the NE PA process, all Federal agencies must include a detailed E IS in every Federal action (such as issuing a permit) that significantly affects the quality of the human environment. If an agency determines that an action will not have a significant impact on the environment, they must publish a negative declaration to that effect. Because fuel alcohol distilleries must obtain a BATF operating permit, they are subject to the NE PA requirements. BATF requires the permit applicant to file supporting environmental information upon which the EIS determination is based. In most cases, an EIS will not be required, and NE PA will not affect the construction of fuel alcohol plants.

The Clean Water Act establishes national water quality goals that are structured around the quality necessary for a variety of uses including public water supplies, the protection and propagation of fish and wildlife, and recreational, agricultural, industrial, and other **purposes. Each State is required to develop and implement, subject to the approval of EPA, a comprehensive water quality management plan designed to achieve the national goals through water quality standards for the designated uses of the receiving waters and through effluent limitations that restrict quantities, rates, and concentrations of chemical, physical, biological, and other constituents that are discharged from point sources. Effluent** limitation guidelines for various categories of point sources are determined by EPA.

Water quality standards and effluent limitations are implemented through State certification programs and through the National Pollutant Discharge Elimination System (NPDES). An applicant for a Federal permit to conduct any activity that may result in a discharge must have State certification that the discharge will not violate any water quality requirements. NPDES is designed to ensure the orderly and timely achievement of the national water quality goals without sacrificing economic or energy goals. Under NPDES, States (or, where State programs have not been approved, EPA) issue permits for discharges on the condition that they will meet all applicable water quality requirements, including State effluent limitations based on the national effluent guidelines.

As discussed in chapter 4, the effluent from fuel alcohol distilleries is very high in biological and chemical oxygen demand and would contribute to water quality problems if not treated or recovered for use as animal feed. In order to obtain a BATF permit for the distillery, the operator must supply BATF with information on the facility's potential environmental impacts. Based on this information, BATF determines whether State certification is necessary. In addition, in most States the operator must obtain an NPDES permit for the distillery. However, effluent guidelines for fuel alcohol plants have not yet been established. Therefore, any restrictions on discharges from these plants must be based on State water quality standards and the best engineering judgment of the permit writer. Within the next year, EPA will prepare an environmental technical report that will serve as the basis for establishing effluent guidelines.

Fuel alcohol plants also could be subject to Clean Air Act regulations on stationary sources. The Clean Air Act is structured around National Ambient Air Quality Standards (NAAQS) that are implemented through a variety of regulatory programs designed to limit emissions of airborne pollutants. The programs most likely to affect fuel alcohol plants include NSPS for industrial boilers and permit requirements designed to prevent the significant deterioration of air quality (PSD) in clean air areas. Although NSPS have not yet been established for industrial combustion sources, many distillery boilers will be large enough to trigger the current PSD permit requirements. However, until NSPS have been formulated it is not possible to determine to what extent the Clean Air Act will affect fuel alcohol distilleries. Larger distilleries also will be subject to the stringent requirements for siting in nonattainment areas. But, most facilities will be located in rural areas and the latter should not pose a major constraint to construction.

Provisions of the Clean Air Act related to mobile source emissions include numerical standards for emissions of pollutants from new motor vehicles or engines as well as the regulation of fuels and fuel additives. Standards have been established for emissions of carbon monoxide, hydrocarbons, and nitrogen oxides from light-duty vehicles and engines. Although gasohol could result in violations of these standards, the adverse effects are not likely to be great, and the violations could be avoided by restricting gasohol use in problem areas or by requiring minor carburetor adjustments. Should a significant adverse impact be found, vehicles using gasohol could be exempted by EPA for purposes of R&D or national security.

The Clean Air Act also requires EPA to regulate automotive fuels and fuel additives through a registration scheme. The manufacturer must petition EPA for registration of the fuel or additive and provide EPA with supporting information including the commercial identifying name, range of concentration or chemical composition, and purpose-in-use. If EPA determines that the fuel or additive will contribute to air pollution that may endanger the public health or welfare or will impair the performance of automotive emission control systems, they can regulate or prohibit its manufacture, distribution, or sale. In 1977, a group of marketers petitioned EPA to register gasohol, and the EPA Administrator determined that there was insufficient evidence to deny the petition. A similar petition for a 2.75-percent blend of methanol with unleaded gasoline was approved early in 1980, but a petition for a blend of up to 15 percent anhydrous crude methanol (75 percent methanol, 5 percent ethanol, 7.5 percent n-propona1, and 12.5 percent i-butanol) recently was denied on the basis of anticipated evaporative emission, phase separation, materials incompatibility, and drivability problems.

Hence, if it became necessary, distillery boiler emissions could be regulated under the Clean Air Act provisions related to stationary sources, distillery effluents can be controlled under the Clean Water Act, and automotive emissions from using ethanol as a fuel additive could be regulated under the mobile source provisions of the Clean Air Act. A possible exception would be if NSPS included a size floor that exempted boilers in alcohol fuel plants.

None of the above regulatory authorities has been exercised as yet because the scientific data necessary to justify regulation are incomplete or ambiguous. Although EPA is researching the environmental effects of alcohol fuels, the fact that legislative interest in promoting gasohol is at its height while the resulting short- and long-term implications of doing so are not yet fully understood reflects a continuing regulatory problem. That is, the Federal Government tends to direct its attention and funding toward existing recognized problem areas and, thus, can give very little attention to long-range planning or to researching emerging and potential future problems.

Crop Residues and Grass and Legume Herbage

Introduction

Although the energy potential of grass and legume herbage and crop residues is not as widely known as that of wood or gasohol, it is considerable. Forage grasses and legumes, such as big bluestem, orchard grass, broom grass, tall fescue, alfalfa, hay, clover, and reed canary grass, could contribute up to 5 Quads/yr of renewable energy by 2000, depending on the availability of cropland, while the crop residues that currently are left in the field after harvesting could contribute more than 1 Quad/yr to domestic energy supplies in 2000. Grasses and residues can be combusted alone or cocombusted with coal or other biomass feedstocks in small boilers or used as the feedstock for gasifiers. Because more oil is displaced by these materials through gasification, this may be the more valuable use. In the long term, however, both grasses and residues— as well as other cellulosic materials — may become more valuable as ethanol or methanol feedstocks.

If the energy potential from grasses and residues is to be realized, both incentives for supply and demand and funding for R&D might be necessary. It is possible that increased oil prices alone will be a sufficient incentive to stimulate demand, which in turn will raise prices and elicit a supply of grasses and residues for energy. Policy initiatives such as education programs and subsidies would accelerate the introduction of these energy sources. This section reviews current policies affecting the production and use of grasses and residues for energy and presents some policy options that could stimulate their use or manage any resulting adverse impacts.

Current Policy

There is little current policy related to grasses and residues. Demand for these materials has never been great enough to necessitate regulating their supply or their manner of use. However, a number of considerations related to their role in overall agricultural, energy, and environmental policy have been raised.

Relative to the resource base, forage crops play a minor role in agricultural policy (as described in the gasohol policy section) to the extent that they can be grown on set-aside lands. In some cases, grasses constitute "approved conservation uses" for set-aside and other production control lands because their sod helps to control erosion. On the other hand, land can only be designated as set-aside if it produced a crop other than hay or pasture within the previous 3 years, unless it was used for forage crops in all 3 years as part of a normal crop rotation pattern.

The policies that could affect the conversion of grasses and residues into energy include those that discourage or restrict new uses of oil or natural gas as well as those that regulate air pollutant emissions from stationary combustion sources.

The Fuel Use Act of 1978, part of the National Energy Act, prohibits (with certain exceptions) the use of oil or natural gas as a primary energy source in new fuel-burning installations and the use of natural gas in existing facilities after 1990. But, these prohibitions do not apply to most cogeneration facilities or to units that have a fuel heat input rate of less than 100 million Btu/hour. Where combustion or gasification facilities would be used for cogeneration or would be relatively small, they will not come under the Fuel Use Act prohibitions and the primary incentive to use grasses and residues as a primary fuel in these facilities would be the cost of oil and gas. Where grasses or residues are cocombusted with coal, however, the facilities could be quite large.

Similarly, the Clean Air Act provisions related to stationary source emissions (as reviewed in the gasohol policy section) primarily

are applicable to larger sources and, for the most part, would not affect biomass combustion or gasification. If technological controls or process changes were required, they could increase the cost of conversion. In addition, it could be difficult to site conversion facilities in nonattainment areas, but because these are usually urban areas and the most cost-effective use of grasses and residues is in rural areas, these will have only a limited effect.

Policy Options

Policy incentives for grasses and residues would accelerate their introduction into domestic energy markets and help reduce the long-term investment uncertainties. The important policy options are those that would ensure the development of and investment in conversion technologies, as well as those that would provide a reliable supply of feedstocks without causing adverse environmental impacts.

Resource Base

While gasohol must compete in traditional markets for starch and sugar feedstocks, there are no established markets for crop residues and about 75 percent of current forage crop production is used onfarm. Thus, links between farmers and conversion facilities need to be established. **It** is likely that the development of conversion technologies such as gasifiers will be a sufficient stimulus to the establishment of a supply infrastructure. At some point, however, **the Government may choose to intervene in the market to ensure that, in the long term, using cropland to produce grass and legume herbage for energy does not conflict with food needs, or to ensure that residue harvesting does not result in increased erosion or reduced soil productivity.**

The two sources of forage crops for energy are increased productivity and production on set-aside and potential croplands. Demands for these crops, stimulated through conversion process subsidies, could be sufficient to increase productivity. If additional incentives are needed, they could include income support programs similar to target prices or deficiency payments, or tax credits or deductions for the costs incurred in more frequent harvesting. For the use of set-aside lands, however, forage grass production would have to be integrated into the existing agricultural policy structure. This could merely take the form of allowing forage grasses to be grown for energy purposes on production control lands aside from their value as an approved conservation use, or forage grasses **could be included** in the general agricultural production control and income support system.

The options that involve income support payments (such as deficiency payments), or that use CCC as the middleman between farmers and conversion facilities, would increase Government program expenditures, but would tend to make the supply **more reliable in that CCC** could monitor production and maintain reserves as a hedge against short-term supply deficits. Alternatively, conversion facilities could establish long-term contracts with local forage producers or could purchase their own crop land.

If demand for food continues to increase, little cropland may be available by 2000 for grass and legume herbage production. Thus, **special attention should be given to R&D support for plant hybrids with high dry matter yields when grown on land that is poorly suited to food crops. So** long as these hybrids do not have significantly higher yields on better quality land, there will be no economic incentive to displace food crop land with them.

Most existing agricultural production represents a potential source of crop residues for energy. They can be harvested after the crop, but this method delays fall ground preparation, and, if fall rains come early, can prevent it altogether and thus delay spring planting. Alternatively, custom operators could work **under contract for farmers.** As **with forage** grasses, an exogenous demand may be sufficient to encourage residue harvesting. If additional incentives are needed they could include cost sharing, attractive financing, or tax subsidies for the harvesting equipment. Again, residues could be bought and resold by CCC or through long-term contracts directly with farmers. Compensation programs should be developed for onfarm storage of crop residue stacks.

Although grass and legume herbage cultivation has a much lower erosive potential than grains and other row crops, achieving high dry matter yields of lignocellulose crops may increase the potential for chemical water pollution from fertilizers. The options for controlling this include education programs, effluent charges, and fertilizer application limits implemented through approved conservation plans or section 208 permits; these are discussed in detail in the gasohol policy section. However, any controls on nitrogen fertilizer use will limit productivity of crops other than nitrogen-fixing plants.

The primary issue surrounding crop residue removal is ensuring that farmers do not harvest too much of the residues and thereby lose erosion protection. Education programs sponsored by the Extension Service probably would be necessary, but not sufficient, because research suggests that it is not within the economic interests of many farmers to protect against soil erosion unless they have extremely long planning horizons and assume a very low discount rate on future income. Therefore, **subsidies for residue harvesting also might be linked to environmental controls** such as mandatory approved conservation plans, or taxes on residue harvest beyond levels determined to protect soils. Again, these options are discussed in detail in the gasohol policy section.

Conversion

If the energy potential of grasses and residues is to be realized in the near to mid-term, Government incentives for the development of and investment in conversion facilities will be necessary. For example, RD&D support is needed to develop gasifiers that can use grasses and residues, to develop inexpensive compaction or pelletization methods to reduce fuel transportation costs and improve handling characteristics, to demonstrate the use of grasses as a methanol feedstock, and to improve lignocellulose-to-ethanol processes. In addition, a full range of tax incentives (such as investment tax credits, accelerated depreciation, or special energy production credits) as well as subsidies such as low-interest loans, cost sharing, or guaranteed feedstock prices should be considered to spur investment. The general implications of these options are discussed in detail in the previous sections. The primary noneconomic incentive to be considered is a guaranteed supply of forage grasses or crop residues for conversion facility feedstocks, implemented either through CCC or direct long-term contracts.

Finally, where cocombustion of grasses and residues results in net adverse air quality impacts, alternative control strategies for these should be developed under the Clean Air Act.

Anaerobic Digestion of Animal Wastes

A review of the analysis in chapter 4 indicates that anaerobic digestion of manure from small confined animal operations could produce approximately 0.27 Quad/yr of biogas--a mixture of 60 percent methane and 40 percent CO,. Although 0.27 Quad/yr is not a large contribution to total U.S. energy demand, it could make many livestock operations energy self-sufficient.

However, several issues must be resolved before anaerobic digesters could be widely used. First, **the basic technological designs should be improved and the biological reactions better understood so that advanced automatic digesters will perform reliably with widely varying feedstocks.** Means of financing digesters that reduce farmers' investment costs also might be implemented. Gas and electric utility rates and practices must be revised in order to provide backup power at a reasonable cost and to purchase excess electricity (or, where applicable, gas) at a fair return. Finally, farmers must be convinced to change their present waste management practices to include anaerobic digestion systems. Fortunately, the necessary changes are consistent with emerging trends in confined animal operations.

Farmers can obtain financial assistance from several Federal agencies to defray digester costs, including DOE and USDA. In genera], this assistance consists of grants, loans, and loan guarantees. Farm investment tax credits also can be used for digesters, but often farmers already will have applied the credits to other equipment.

Manure-handling practices are federally regulated under Clean Water Act provisions related to both point and nonpoint sources. The general framework of the Act is described in the gasohol policy section. EPA has established effluent limitation guidelines for the point source category of "feedlots." This category includes most forms of livestock operations such as open and housed lots or barns with relatively large numbers of animals (e. g., 1,000 head of cattle, 700 dairy cows, 2,500 swine, 55,000 turkeys). I n general, these regulations establish a zero discharge limit for new and existing feedlots unless the discharge is to a sewage treatment plant.

Livestock operations of al l sizes can be regulated under the Clean Water Act's section 208 provisions for nonpoint sources. However, as discussed under alcohol fuels policy, section 208 is only now being implemented and it is not clear what BMPs to control manure-related runoff will be. **Including anaerobic digestion as a BMP probably would accelerate introduction of the technology.**

In addition to the provisions of the Clean Water Act, manure-handling practices also are regulated under State laws. State requirements vary widely; they may include permits, minimum runoff storage capacity, maximum land application limits, and odor and dust regulations. Some States also offer income on investment tax credits or other financial incentives (e. g., grants, loans) for anaerobic digestion systems, as part of either State environmental or energy policy. For larger systems with high initial investment costs, **innovative financing schemes such as leverage leasing may accelerate digester use.**

In general, the Federal and State regulations related to manure-handling practices have the potential to encourage anaerobic digestion because they provide a strong incentive to change such practices; surveys reveal that a demonstrated need for such change is a major obstacle to farmer acceptance of anaerobic digestion. [19] Financing for both the implementation of Federal and State regulations and for new manure-handling systems would help to increase farmer acceptance.

Utility policies may also pose an obstacle to digester use. Existing rate structures both for providing backup power and for purchasing surplus power discriminate against small indi-

[19] R H Cole, et al , "A Survey of Worcester County, Massachusetts, Dairy Farms With Respect to Their Potential for Methane Generation, *Science Technology Review*, September 1976 27-45

vidual energy sources such as digesters. Some of these utility policy issues will be resolved by implementation of the Public Utilities Regulatory Policies Act of 1978, part of the National Energy Act. Others may require additional legislation. Policy options related to these issues are discussed in detail in OTA's forthcoming study of dispersed electric generation and are not discussed further here.

Probably the most important policy options for anaerobic digestion are RD&D support **for the demonstration of a wide range of inexpensive and reliable digester systems and the implementation of attractive financing schemes.** Once farmers have been shown that reliable, automatic, and relatively inexpensive digesters are available, and that these systems will solve environmental problems stemming from current manure disposal practices, the primary obstacle to anaerobic digestion — farmer acceptance—will have been removed. From that point, existing incentives such as DOE and USDA loans and grants, as well as available tax credits and deductions, should be sufficient, especially if they help farmers overcome the high initial investment cost for digesters. Finally, it should be recalled that Federal subsidies for conventional energy sources are substantial. These subsidies make both the internal and external costs of individual energy systems such as digesters seem relatively greater than they are.

Conclusion: Biomass and National Energy Policy

The United States today confronts several broad policy issues with respect to bioenergy development: 1) whether to adopt policies to promote the growth of bioenergy beyond those levels that will be reached through the operation of market forces in conjunction with incentives and subsidies that already have been approved; 2) whether to change the character or size of existing incentives and subsidies that affect bioenergy; and 3) whether to adopt new policies to manage the impact on soils, forests, the environment, and society that will accompany the growth of these new sources of energy.

A key conclusion of this report is that there is a great deal of biomass in the United States that can be converted to useful energy— much more than most people realize— and it can be brought into production quite rapidly if necessary. OTA estimates that as much as 5 to 6 Quads/yr of bioenergy will be used by 2000 if prices remain stable (in real terms) at 1980 levels, or increase moderately, and if Government promotional activities remain more or less as they are today. This means that the contribution of energy from biomass **will more than triple in less than 20 years even if little or nothing new is done. OTA's confidence** in this estimate is based on the fact that it projects a continuation of current trends and the expected growth would take place primarily in the forest products industry and in home heating applications where technologies are already well known and in use.

Growth of bioenergy beyond this level, however, is likely only if prices increase significantly or if America adopts policies to promote a much more rapid expansion. Those who support such a course of action do so chiefly on the grounds that bioenergy would help displace imported oil and would hasten the transition to reliance on renewable resources. Assuming a major national commitment to this goal, OTA estimates that the resource base will sustain the production of as much as 12 to 17 Quads/yr of energy.

The objective in this chapter has been to point out those considerations that should be taken into account in making choices about the speed and character of bioenergy development and to describe and analyze specific actions that might be taken by the Federal Government to further promote and guide that development. The pages that follow summarize the key policy alternatives that have been identified.

As noted, Congress already has passed a number of measures to support the development of new resources of energy of all kinds, and many of these have improved the prospects for investment in bioenergy. The most important of these provide for the phased deregulation of crude oil and natural gas prices. **Because of the wide range of feedstocks and conversion technologies involved, however, many bioenergy systems can benefit from policies more carefully tailored to the needs of the producers and users of this form of energy.** Although some legislation with this objective has been passed, a number of additional options should be considered.

In the case of wood, a principal concern is the management and care of the resource base —the Nation's forest lands. One of the reasons that wood energy is attractive is the possibility that increased demand for it will lead to more intensive forest management, and thereby to an increase in the quantity and quality of available timber. Unfortunately, however, it is not certain that this will occur, or that the many kinds of environmental damage that may result from wood harvesting, transport, and conversion, can be avoided. Therefore, **an increase in the use of wood energy should be accompanied by new and expanded programs and incentives to encourage–and perhaps even require–good forest management practices, including much more extensive assistance to, and cooperation with, State forestry agencies.**

The need for supportive Government programs is especially great outside the forest products industry where inexperience with wood energy may delay its adoption even when it is cost effective. Programs to provide information and technical assistance in con-

version are needed for these users, as are improved inventories of national and local forest biomass resources and loan guarantees and tax credits to help **overcome the higher capital cost of wood combustion systems. Incentives to support the establishment of commercial wood supply systems in the private, nonindustrial forests also would encourage** wood energy use. Where possible, the Federal and State governments might promote wood use by establishing concentration yards and making available a guaranteed supply of Government-owned logging slash and the residues of site preparation, fire prevention, and stand **improvement activities.**

The precise impact of policies designed to promote the use of wood for energy is difficult to estimate. As is the case with many unconventional energy sources, the most important determinant remains the price of conventional fuels. Nonetheless, as wood energy use competes with demand from forest products industries, the continuing problem of supply unreliability and regional price fluctuations may act as a significant additional deterrent to conversion.

The policy issues raised by gasohol are more complicated. The range of available feedstocks extends from wood itself to grass and legume herbage, crop residues, feed crops, and food-processing wastes; these in turn are governed by a variety of legislative, regulatory, and administrative policies and jurisdictions that affect both production and use. Should the United States choose to promote the rapid expansion of the use of gasohol made with ethanol from grain and sugar crops, policy support will be needed to: 1) ensure that feedstocks are available without causing unwanted inflation in the food and feed markets; *2)* increase investment in distillation, distribution, and blending; and 3) manage the resulting impacts on the environment and society as a whole.

A major Federal subsidy, in the form of exemption from excise taxation, already has been granted to gasohol blended from either ethanol or methanol provided that it includes at least 10 percent alcohol produced from biomass sources. Sixteen States have added subsidies that range from 1 cent (Connecticut) to 9.5 cents (Arkansas) per gallon of gasohol. When combined with available investment tax credits and crude oil entitlements, these have made ethanol economically competitive when used as an octane booster, and gasohol made with grain ethanol is now on sale in many parts of the country. Finally, as part of the response to the Soviet invasion of Afghanistan, President Carter has set as a national goal the production of 500 million gal/yr of ethanol by the end of 1981, and has indicated his support for legislative proposals to expand subsidies and extend their duration.

The prospect of an expansion of gasohol production raises a number of important policy issues. Perhaps the most important of these is the problem of assuring the availability of ethanol feedstocks while moderating the impact of this new demand on the price of food and feed. Indeed, managing the consequences of the emerging interdependence between agriculture and energy is likely to remain a key challenge to policy makers responsible for programs in both areas for many years.

The general sources of ethanol feedstocks are expanded production on lands not presently under cultivation, production on lands freed by crop substitution, and commodities diverted from export markets. However, direct competition for feedstocks between ethanol producers and feed, sugar, and export buyers would increase the price and decrease the supply of commodities in all markets.

Encouraging the cultivation of idle lands, including lands now in production control programs as well as potential cropland of many kinds, also introduces problems. These lands often are not cultivated because they are inaccessible, highly erosive, or experience problems with drainage, seepage, or flooding. The cost of special incentives needed to bring them into cultivation, if paid by the public, would constitute an additional but less visible subsidy to alcohol production.

Whatever approach is chosen, careful management of agricultural programs will be necessary in order to minimize the potential undesirable economic and environmental consequences of using grain and sugar crops for ethanol. Up to 1 billion to 2 billion gal/yr, these consequences may be minor. Once ethanol production approaches this amount however, the effects of programs designed to increase grain ethanol production should be reevaluated. If, following such an evaluation, it appears that significant food-fuel competition has begun to occur, a number of changes in existing policy may be desirable to prevent large increases in the price of food and feed. Even before this limit is reached, however, significant new policies may be necessary to minimize the potential environmental effects of ethanol feedstock cultivation.

Despite these potential problems, ethanol from grains is likely to remain important for several years as a means of diversifying U.S. liquid fuel supplies and of encouraging energy self-sufficiency in agriculture. However, if the United States chooses to move quickly to the development of gasohol as a significant source of liquid fuel, while avoiding increases in food prices, careful consideration should be given at the outset to an early shift to methanol (and possibly ethanol) from wood and lignocellulosic feedstocks. Also important here is the development and demonstration of means of converting grass and other herbage to methanol and the further development of lignocellulose-to-ethanol processes. *

Policies and programs to promote the production and use of gasohol raise a number of other policy issues that deserve attention. These include, among others:

- **The nature of the alcohol subsidy. —** In general, good policy instruments signal to the consumer the full cost of the product being used. Current gasohol subsidies, especially if they are continued for long periods into the future, contravene this concept and instead force the general public to subsidize the consumption of automotive fuel. The signal to the consumer— that gasohol is cheaper than it really is — is false, and will lead to greater consumption of the resource, which may run counter to overall national energy goals. Another way of accomplishing the same objective is by mandating alcohol blending at gasoline terminals and allowing a pass-through to the gasoline consumer of the full cost of the blend.
- **The duration of the alcohol subsidy.–-To** promote further investment in distillery capacity, it may be desirable to extend the excise tax exemption granted to gasohol beyond its current expiration date of October 1, 1984. However, many policymakers argue strongly in favor of strict limitations on the tenure of any energy subsidy, and these arguments must be weighed alongside those supporting continued investment in gasohol production. Note that a continuation of inflation can be expected to reduce the value of the subsidy over time.
- **The treatment of imported alcohol.–-Cur**rent legislation allows the blenders of imported alcohol to qualify for the subsidy. Large-scale imports of alcohol would have the consequence of creating a substitute foreign dependence, but this probably would be minor in terms of overall fuel use and would almost surely represent a diversification of energy import sources (e. g., from OPEC members to countries such as Brazil) and would lessen the impact of gasohol use on domestic food markets.
- **The blending of varied amounts of alcohol. —** The octane-boosting properties of alcohol can still be utilized when it is blended with gasoline at percentages lower than 10 percent and the resulting fuel may cause fewer problems in automobiles using it. Accordingly, there is little reason to maintain the current requirement that a full 10-percent blend be produced to qualify for the subsidy.
- **The subsidization of onfarm production and use of alcohol. —** Because current subsidies accrue only to alcohol blended with gasoline for use as a commercial motor fuel, onfarm use of alcohol receives no support. One way to remedy this is by replacing the excise tax credit with a direct tax

*Should the technology be developed for economical conversion of lignocellulosic feedstocks to ethanol, it might replace methanol; but only the methanol conversion process for these feedstocks is ready for immediate deployment credit to the producer. Although there are a number of reasons why farm energy autonomy is attractive, these should be weighed against the increased fuel savings that would be achieved by the country as a whole if alcohol is used as an octane booster in the national gasoline supply stream rather than in pure form as a standalone fuel.

- **The adjustment of the automobile fleet to accommodate alcohol blends.– Experiments indicate that at blends as low as 10 percent alcohol some cars will experience difficulties. There may also be problems of corrosion of parts** in **cars as well as** in blending and transport facilities (these are somewhat greater with methanol than with ethanol), and the Government may want to consider means of assuring that automobiles are adapted to avoid these problems in the future. Early disillusionment with gasohol as a result of problems of this kind — problems that may only appear after the expiration of new-car warranties — may prevent the rapid acceptance of this fuel blend.
- **The passage of regulations to ensure maximum displacement of imported fuel and the most favorable net energy balance. — Of particular importance, in this respect, is requiring** the use of solar energy, coal, or biomass fuels in new distilleries built to produce alcohol for gasohol and requiring that the alcohol be blended with a lower octane gasoline than that which the gasohol displaces.
- **The introduction of methanol to the liquid fuel system.—** For a number of reasons, methanol produced from wood, grasses, residues, and other plant feedstocks appears to be an attractive option. Therefore, a careful study should be made of the best ways of introducing methanol to the liquid fuel system of the country, from the fuel production and distribution system to the various end uses.

In the design of national policies to promote and manage the development of bioenergy a number of broad considerations are worth highlighting. The first is that the actual effectiveness and impact of policies, whether promotional or regulatory, are extremely difficult to anticipate. Because of this it is of the utmost importance that this uncertainty be acknowledged at the outset by making any commitments tentative and including in legislation, where appropriate, detailed provisions concerning subsequent monitoring and assessment of results. It is also important to avoid the pitfall of granting large or permanent subsidies that will distort the allocation of economic resources in the future. Such measures as "sunset" provisions, price and quantity thresholds for subsidies and incentives, and statutory requirements for review of existing policies are means that may be employed to accomplish these goals. A graduated phase-out of incentives for alcohol production, for example, might begin when imported oil costs $35/bbl (1980 dollars) or in 5 years, whichever came first. Formal review of wood energy systems and the condition of the forests and soils might be required when USDA determines that 5 Quads of wood and other lignocellulosic feedstocks are being consumed annually. Regulatory measures designed to protect the environment serve best if they are spelled out clearly at the outset of a new kind of economic activity, and not imposed on investors after they have committed themselves. This is especially important in the case of bioenergy because the environmental impacts of harvesting and use are so complex and potentially far-reaching. Finally, particular attention to the degree of premium fuel displacement achieved in production and consumption is needed if the development of bioenergy is to reduce the dependence on imported oil.

Appendixes

Appendix A: KEY TECHNOLOGICAL DEVELOPMENTS NEEDED TO HELP REACH THE BIOENERGY POTENTIAL

The 1985 bioenergy potential probably can be achieved with relatively direct development of existing technology, but the quality and success of these developments will influence the ease with which the potential is achieved. In the longer term, there are numerous possible developments that could improve the potential for energy from biomass and help to make it an increasingly attractive energy option. In addition, basic and applied research in areas directly and peripherally related to bioenergy can increase the body of knowledge on which new and successful developments ultimately must be based,

Some of the general areas of technological development that could be important to bioenergy use are listed below. The basic criteria used in choosing these are that: 1) the RD&D probably can produce usable results, and 2) it addresses an area that either constrains bioenergy development or shows promise for important new applications of biomass for energy. Although all of this RD&D can be carried out simultaneously, the areas are divided into near and longer term needs, based on the time it may take to achieve commercial applicat ions.

Near Term

Resource Base

- **Wood harvesting.** –A repertoire of wood-harvesting techniques and equipment should be developed. The goals should be to minimize occupational safety hazards, esthetic and environmental damage, and costs, particularly when handling small pieces of wood. Additional goals should be to ensure that the potential benefits (e.g., increased growth of commercially valuable timber) accrue as well as to improve the economics of harvesting and collecting low-quality wood from small tracts of forest.
- **Surveys.**– Surveys should be conducted to determine more accurately the biomass resource, and subregional supply-demand curves for various types of biomass should be developed. This should include the present and projected availability of cropland and potential cropland for energy production and the costs associated with using it.
- **Impacts of biomass supply uncertainties.** -A common feature of most biomass fuels is the uncertainty in supply. For most sources this will primarily be a local, short-term uncertainty caused by fluctuations in weather and local demand. But for grains and sugar crops, considerable uncertainty also surrounds future world demand for food, future crop productivity, and the ability of agricultural policy to stabilize farm commodity prices as the supply of good cropland that can easily be brought into production diminishes. These uncertainties should be investigated to determine their impacts on the biomass supply sectors — particularly agriculture— and on the way that fuel users will respond in order to reduce their risks. The emphasis should be on developing policy options that can better deal with these uncertainties.
- **Biomass storage and transport.** — Inexpensive means of compacting, storing, and transporting wood and particularly herbage and crop residues should be investigated in order to overcome the problems associated with the low energy density (energy per cubic foot) and poor handling characteristics of these materials.

Conversion Technology

- **Methanol from wood, grass and legume herbage, and crop residues.**— Conversion processes for producing methanol from grass and legume herbage and crop residues should be demonstrated, while those for producing methanol from wood should be developed further in order to decrease costs and increase the efficiency (i. e., greater carbon monoxide-hydrogen yields and lower char and oil formation). Furthermore, small-scale conversion facilities (less than 150 green ton/d input) should be developed in order to gain access to a larger fraction of the biomass resource. (A larger portion of the resource is made accessible with small conversion processes because the dispersed nature of biomass makes it easier to collect small amounts for conversion than to collect the large quantities required for large-scale conversion facilities.)
- **Airblown gasifiers.**— Various sizes of airblown gasifiers should be developed and demonstrated in order to improve the technology and gain operating experience.

- **Wood stoves.**– Wood stoves should be developed further to increase their efficiency and ease of operation and to reduce emissions, safety problems, and maintenance. This should also include the investigation and development of heat storage devices that can provide a steadier, more even flow of heat from wood heating systems.
- **New direct combustion technologies.** – New direct combustion technologies for wood and other feedstocks that show promise for increased efficiency and decreased emissions in industrial applications should be developed and demonstrated.
- **Ethanol from wood, grass and legume herbage, and crop residues.** — Development of processes for economically converting wood and herbage (including crop residues) to ethanol should continue. While most of the processes are not currently ready for demonstration, those that are ready and appear to be feasible should be demonstrated.
- **Anaerobic digesters.**– A variety of onfarm anaerobic digester systems should be demonstrated. The goals should be to lower installation costs and improve the digesters' reliability and flexibility.
- **Onfarm fuel production.**--Onfarm ethanol production may be popular as a means for farmers to achieve some degree of liquid fuel self-sufficiency and to divert crops in times of low prices. If so, then the maximum amount of oil can be displaced by using these crops to produce dry ethanol as an octane-boosting additive to gasoline. In order to do this onfarm, relatively automatic distilling equipment capable of producing dry ethanol safely and inexpensively should be developed. For dry and wet ethanol production, facilities should be developed that are capable of producing dry distillery byproduct and using wood and herbage as a fuel. Solar-powered distilleries also should be developed.

  There is, however, a mismatch between ethanol and farmers' liquid fuel needs (e. g., diesel fuel). Although this can be overcome with modifications in the farm equipment, other possibilities for onfarm fuel production also should be investigated. One example may be cultivation of sunflowers and the development of small presses that can be operated easily and inexpensively to separate the sunflower seed oil for use as a diesel fuel substitute, The research should determine which farming operations are best suited to onfarm fuel production, how many of each type of operation exists in the United States, and what fuel and energy savings can be achieved in each category. The emphasis should be on providing a repertoire of possibilities from which individual farmers can choose the alternative best suited to their needs.
- **Large-scale ethanol production from grains and sugar crops.** — If grains and sugar crops are to be converted to ethanol, methods for reducing the distillery energy usage and other ethanol production costs should be developed. The most important, at present, appear to be the development of means for storing sugar crops without deterioration of the sugar due to bacterial attack, processes for continuous fermentation that can be operated reliably without the need for redundant equipment, and new means for removing the ethanol from the fermented solution (distillation is used at present).

  Dry milling processes also should be investigated because of their potential for reducing the investment cost for distilleries capable of producing a distillery byproduct (corn gluten) that can be used in higher proportions in animal feeds and for different animals than distillers' grain.

End Use

- **Use of alcohol-gasoline blends.**– The problems associated with using blends of either methanol or ethanol and gasoline should be investigated further. Techniques for keeping the blends dry should be developed. The automobiles and engine designs most likely to be adversely affected by using the blends should be identified, the type and cost of necessary modifications should be established, and attempts should be made to identify or develop low-cost additives that minimize the adverse effects. Similar studies of the distribution systems should be carried out,

  Because of the potentially greater problems associated with methanol (as compared to ethanol) blends and the possibilities for producing significantly larger quantities of methanol than ethanol in the 1980's, the use of methanol fuel should be examined carefully. The entire system including oil refineries, distribution systems, and various end uses should be examined with respect to costs and oil savings to determine which strategies are best suited to introducing methanol into the liquid fuels system,
- **Data for National, State, and local decisionmaking.** –An important feature of bioenergy is that feedstock availability and cost vary considerably with time and geographic location. Local data and analyses should be developed that calculate the costs of using the local biomass for energy and the effects of the supply and cost variations

on the economics of using biomass. These models also should contain information on the local supply, type, and variation in supply of the biomass resource. This could aid individuals and businesses in making informed decisions on a site-specific basis as to whether or not to utilize this resource for energy. This will involve considerable survey work.

Longer Term

Resource Base

- **Crop switching.** — Various crop-switching possibilities that involve fuel production should be investigated further. One example is the cultivation of corn instead of soybeans. The byproduct of producing ethanol from the corn can then be substituted in animal feed for some of the soybeans not produced. Other possibilities include the cultivation of sugarbeets used for animal fodder. The crop-switching possibilities should be explored to determine the extent to which they can be used to produce fuels from agriculture without expanding the quantity of cropland cultivated. Included in this should be investigations of the effect of substituting current feed rations with varying amounts of forage — distillers' grain, and forage-corn gluten mixtures.
- **Crop development.** — A wide variety of crop types should be developed, including grasses, legumes, and trees; freshwater and saltwater plants; plants that produce or can be converted to liquid fuels suitable for transportation; and plants that can be cultivated on lands that are or may become unsuitable for food or feed production. Cultivation techniques (especially for aquatic plants) and the development of plant hybrids require special attention, because these unconventional crops are likely to have both unique potentials and problems. The criteria should be the net premium fuels (oil and natural gas) displacement per acre cultivated (for land-based plants), the utility of byproducts, the economics, and the environmental impacts. At the same time high-yield forage grasses and legumes should be developed, so as to free more pastureland for energy product ion.
- **Ocean farms.** — R&D into the engineering criteria for ocean kelp farms is needed to better understand, among other things, the stresses that such a farm would be subject to, how to build the farms economically, how to protect the kelp from storms and strong currents, and how to minimize the loss of nutrients applied to the farm.
- **Environmental impacts of biomass cultivation.** –The long-term environmental impacts of cultivating short-rotation trees on forestland and farmland and of whole (aboveground) tree removals from forestland should be investigated. The emphasis with respect to whole (above--ground) tree removals should be on its effect on the forest's nutrient balance and soil organic matter, and any subsequent long-term effects on the forest's productivity and capability of resisting stresses.

  Because grasses and some other perennial crops currently appear to be the most environmentally benign crops for cropland and because there is excellent promise for improved yields from these types of plants, screening and development of fast-growing perennial crops such as some grass and legumes could have a positive environmental impact. The emphasis should be on high-yield grass and legumes that can be cultivated easily and economically on a variety of cropland types with a minimum of fertilizers and pesticides.
- **Indirect costs.**–- Methodologies should be developed to help establish the indirect costs associated with bioenergy, particularly the competition with food and feed, the effects of increased forest management, the potential competition with the production of traditional forest products, and the effects on foreign trade. Developing the data needed for these analyses probably will involve considerable survey work.
- **Photosynthetic efficiency.**– Basic research in photosynthesis and plant growth should be continued to determine the efficiency of plants in converting basic photosynthetic material (photosynthate) to other products (e. g., cellulose, organic carbon, hydrogen, and oils) and to better understand the effects of various stresses (water shortage, heat, cold, poor soil, etc.) on plant growth. Research should also address the reasons for the low photosynthetic efficiency of plants and ways to improve it.

Conversion Technology

- **Thermochemistry of biomass.**–-The chemistry involved when biomass is combusted, gasified, or liquified, as well as secondary gas phase chemistry should be investigated. Substantial process and efficiency improvements and new applications in the production of chemicals and fuels from biomass could result.
- **Chemistry and physics of lignocellulose.**--- Investigation of the chemical and physical properties of lignocellulosic materials (e. g., wood,

grasses, legumes, and crop residues) should continue. New ways of separating the various components of lignocellulose from one another or exposing them to chemical attack should be researched and developed. Inexpensive pretreatment that make fibrous materials easier to handle should be investigated.

- **Biochemical conversions. — The biology and** biochemistry of the biochemical conversion processes (e. g., fermentation, hydrolysis, and anaerobic digestion) should be researched in detail so that these processes can be better understood and therefore controlled and manipulated. Various biomass feedstocks should be investigated, novel techniques (e. g., matrix immobilized enzymes) explored, and new types of bacteria and yeasts developed (e. g., by molecular and traditional genetics).

End Use

- **Uses for aquatic plants. —** Because of the possibility that large quantities of saltwater and freshwater plants may be available in the long term, techniques for harvesting the plants and suitable conversion technologies (e. g., anaerobic digestion) should be developed. Because large quantities of these plants are not likely to be commercially available for some time, basic and applied research into the fundamental physical, chemical, and biological properties of these plants should precede more advanced development efforts. The possibilities for very high yields from aquatic plants and the possibility of large aquatic energy farms (e. g., in the ocean or on land unsuitable for land plants) probably justify an active RD&D program even though many current concepts are speculative.
- **Use of alcohol fuels.– Alcohols appear to be the** liquid fuels that can be produced most easily from the biomass feedstocks in greatest supply. These can be converted further to liquids that are compatible with gasoline, but the conversion processes inevitably involve additional expense and energy loss. Consequently, vehicles capable of accepting fuels that may vary from pure gasoline to pure alcohol and all of the intermediate blends should be developed; the changes needed in the liquid fuels distribution system to accommodate alcohols should be assessed; and the alcohol-to-gasoline processes should be investigated in order to judge which is the least expensive long-term option for the consumer.

Other

- **Basic and applied research in peripheral areas. —** Basic or applied research in one area is never isolated from peripheral areas of research. The success of research usually depends on the body of knowledge being developed in related areas and often depends on the results in areas which, at first, seemed totally unrelated. Consequently, the quality of the results and the ultimate success of bioenergy research is likely to depend on the support given peripheral areas of research. These areas include the biochemistry and biology of plants, the chemistry (including thermochemistry) of organic materials, and the physics of biomass. No one can predict which areas ultimately will prove to be of fundamental importance to long-term developments. Bioenergy development, however, probably will be enhanced by supporting a wide range of basic and applied research in areas peripheral to the basic objectives.

Appendix B: MODEL DESCRIPTION

A stochastic simulation model was used to evaluate and compare the implications of the options for producing gasohol and modifying current commodity programs on economic variables characterizing U.S. corn and soybean markets, FEEDSIM, a model of U.S. corn and soybean markets is comprised of annual production, demand, and Government program components, and incorporates interaction in supply and demand for both commodities. Because FEEDSIM is documented in detail elsewhere, only those modifications that were necessary to address the gasohol policy options are discussed here. Those modifications include incorporating: 1) the commitment by CCC to supply grain to alcohol distillers, 2) the subsidy needed to make alcohol production competitive, and 3) the impacts on soybean demand resulting from increased supplies of distillers dried grain.

The gasohol program alternatives analyzed here require a corn supply commitment equivalent to that needed to produce 1, 2, 3, or 4 billion gal of alcohol — 385, 769, 1,154, and 1,538 million bu of corn, respectively. These amounts can be compared to the 460 million bu of corn that a previous study estimates could have been produced on corn acreage withdrawn from production in 1978.[2]

The alternative levels of supply commitment are purchased and sold by CCC. This modification is incorporated in the stocks component of the model by specifying that CCC make available that amount of grain from either inventories accumulated through nonrecourse loan defaults or purchases from the market, which equal the difference between the levels of supply commitment and quantity defaulted. CCC is charged the loan rate for grain withdrawn from inventories and the market price for grain purchased from the market.

The per bushel corn price used to calculate CCC revenues is that required to make gasohol competitive with gasoline—$0.75/gal in 1979 This amount is increased 10 percent annually in following years to reflect rising gasoline prices. The subsidy for gasohol production is equal to the difference between the average price CCC is charged for the grain supply commitment and the price for grain that makes gasohol production competitive.

The process of grain to alcohol conversion also results in the production of distillers dried grain — a protein source that substitutes for soybean meal at a rate of 2 to 1.* Each bushel of grain used in gasohol production reduces domestic soybean demand by 0,19 bu.**

[1] Forrest D. Holland and Ronald L. Meek hot *FEEDSIM Description and Computer Program Documentation* Agricultural Experiment Station, Purdue University Sta Bul No 2.21, March 1979

[2] S. Barber, et al. The Potential of Producing Energy From Agriculture ( ) [A contractor report May 1979 The analysis reported here does not incorporate wheat that could have been produced on acreage withdrawn from production in 1978 The study cited estimates this amount to be 220 Million bu Research conducted by the authors found that annual supply commitments of this level resulted in substantial dislocations in the wheat sector

* Distillers dried grain requires additional processing from the corn slurry It is highly competitive with soybean meal and more transportable than the corn slurry

**Modifications Incorporated in the model specify full utilization of the distillers grain as a protein substitute for soybean meal While this is not likely, the modification was done in this manner to illustrate the most severe case it is more likely that some of the distillers grain would be fed wet as a corn substitute To the extent that the corn substitution occurred, soybean demand would be diminished less than indicated in these results The results shown here should be interpreted with this factor under consideration Other limitations of the model include the exclusion of acreage responses from other feedgrains and other sources of adjustment that may in the long run ameliorate the increased demand levels and stockholding by alcohol distillers to buffer severe supply and demand conditions

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