Chapter 3

ISSUES AND FINDINGS

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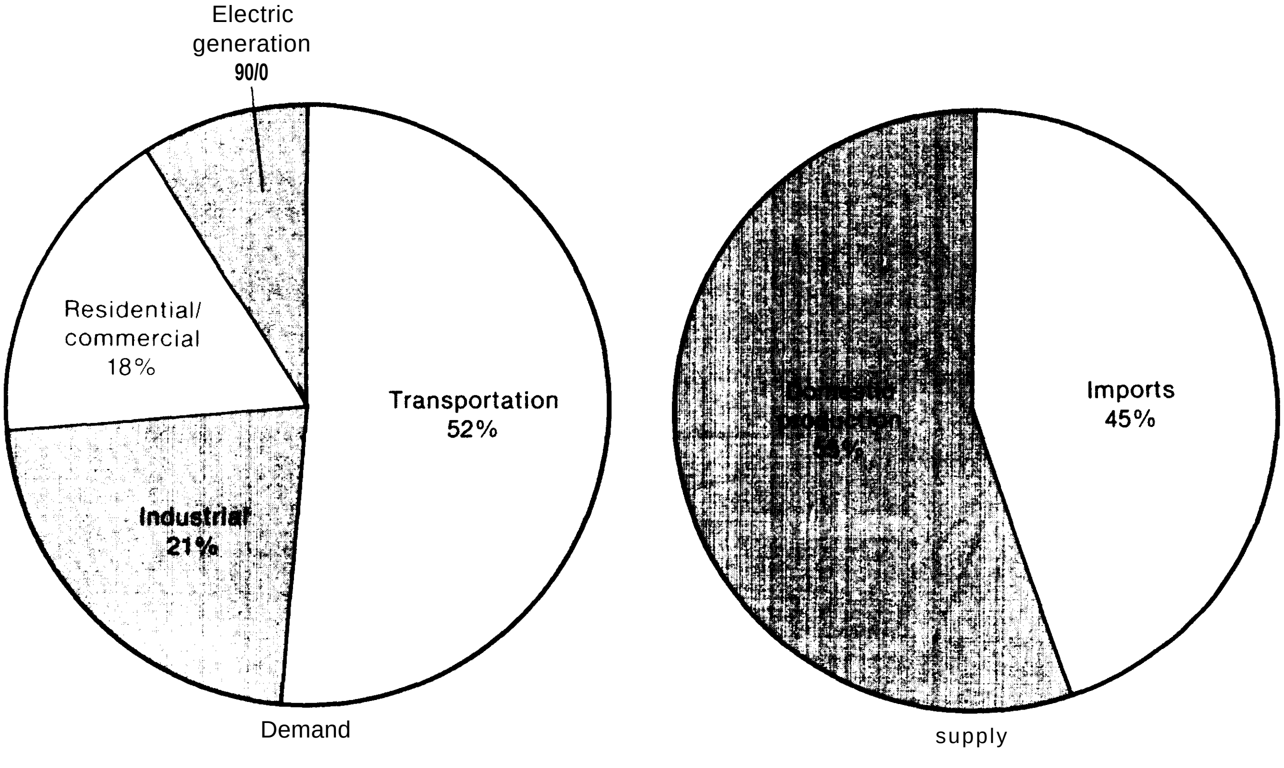
How Much Energy Can the United States Get From Biomass?

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



Demand

supply

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.

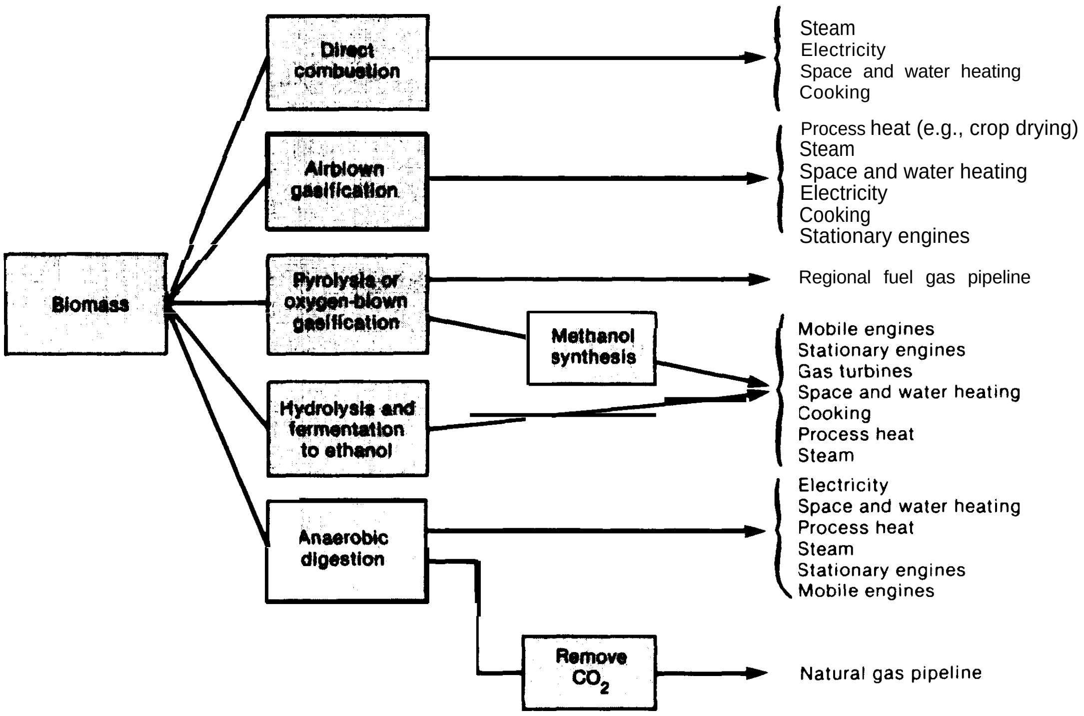
Wood From Commercial Forestland

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

Figure 5.—Fuel Uses for Biomass



SOURCE Office of Technology Assessment

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*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

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

		Gross energy potential’ (Quad/yr)		
Source	Biomass	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] (I-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]

[a] Does not include deductions for cultivation and harvest energy, losses. or end-use efficiency

[b] These Categories are not additive because they use some of the same land

[c] Assuming 4-ton/acre-yr yield in 1985 and 6-ton/acre-yr in 2000.

[d] Upper 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 Office 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.

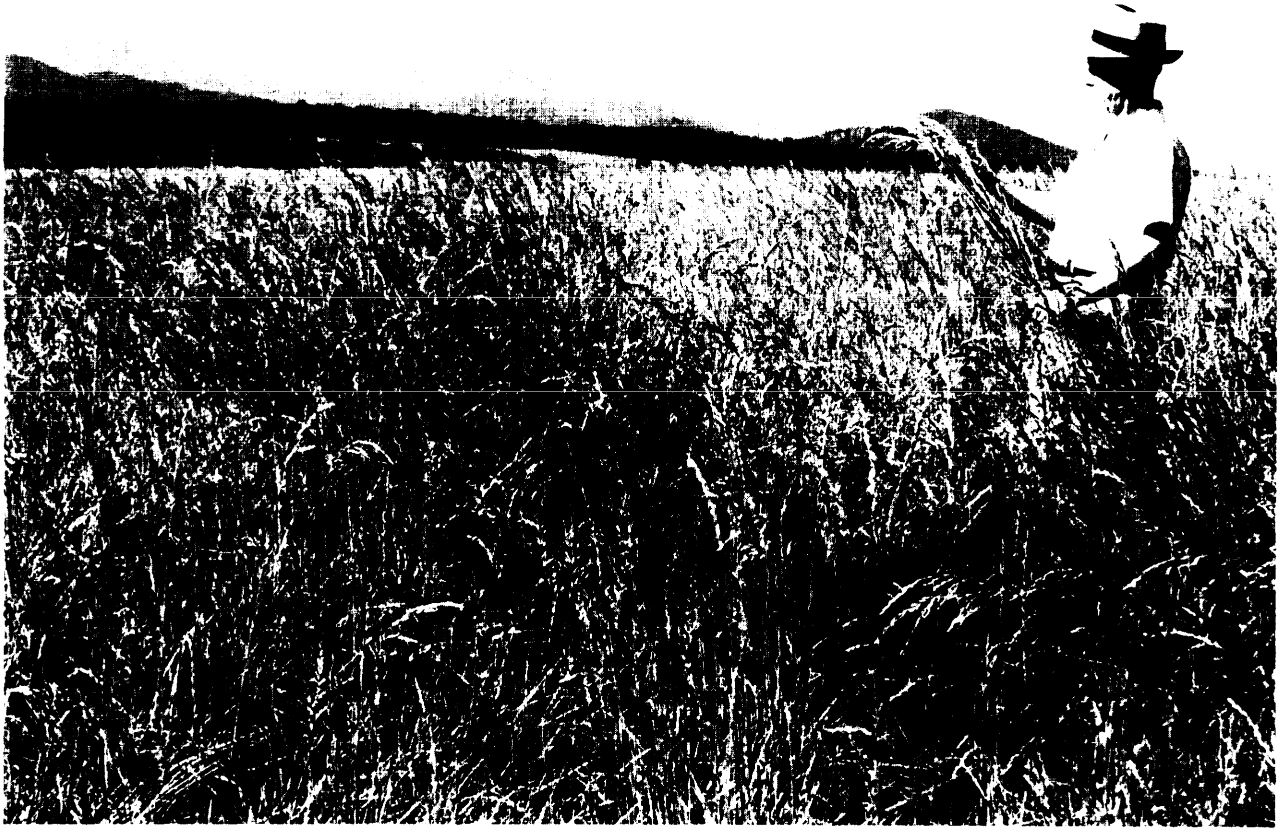

Photo credit USDA, David Brill

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.

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

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*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)

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.

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[1] *Energy* From Ocean Kelp Farms (Washington, D C Off Ice of Technology Assessment, draft, June 1979), to be published as committee 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 animal operations and thereby influence the energy obtained from animal 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.

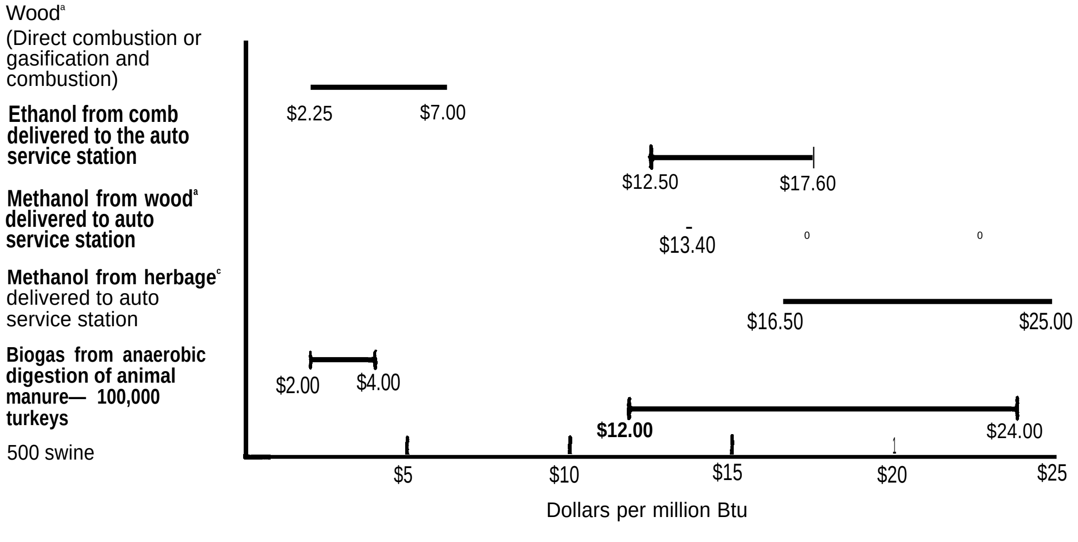
What Are the Economic Costs and Benefits of Biomass Fuels?

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-

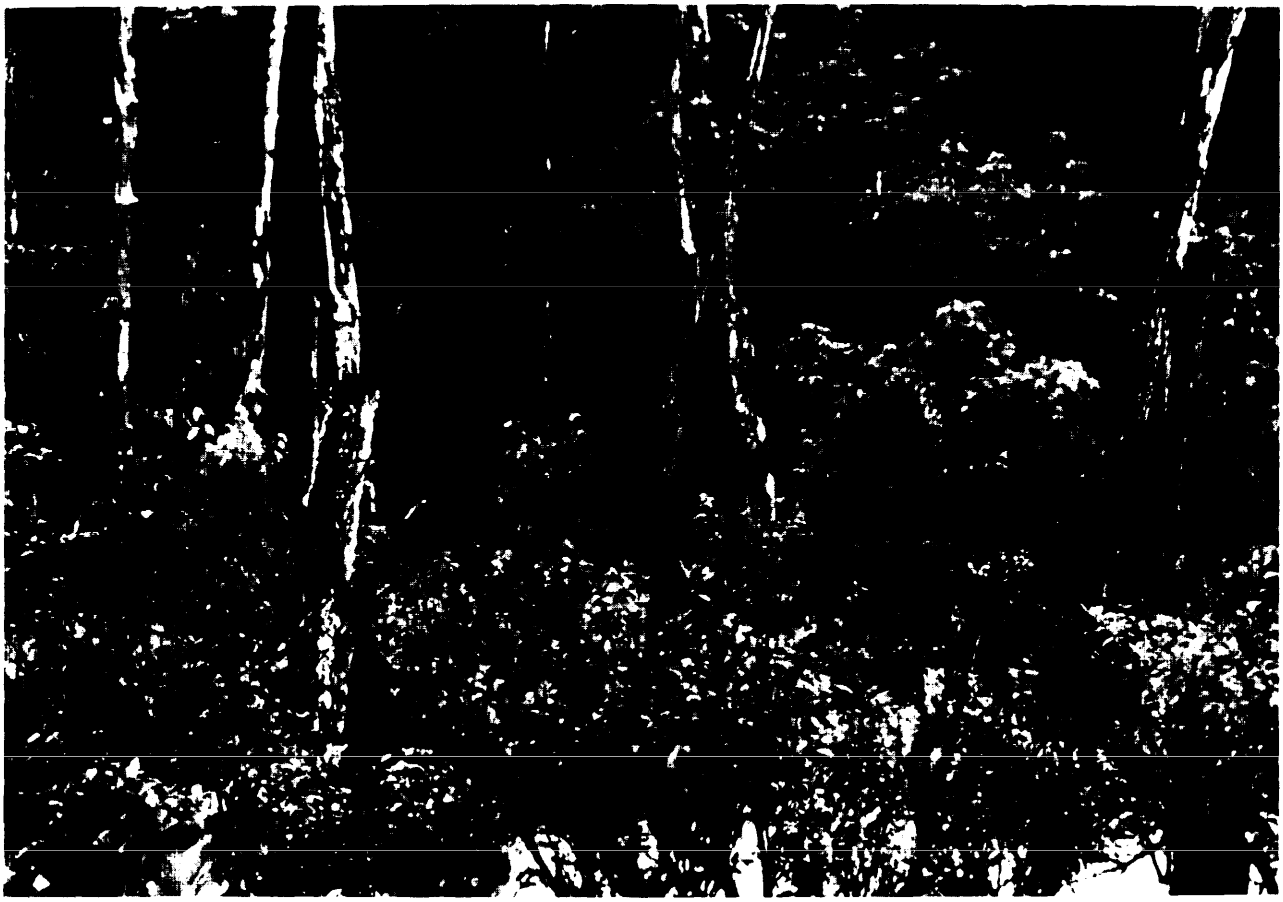


Photo credit Department of Energy

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.

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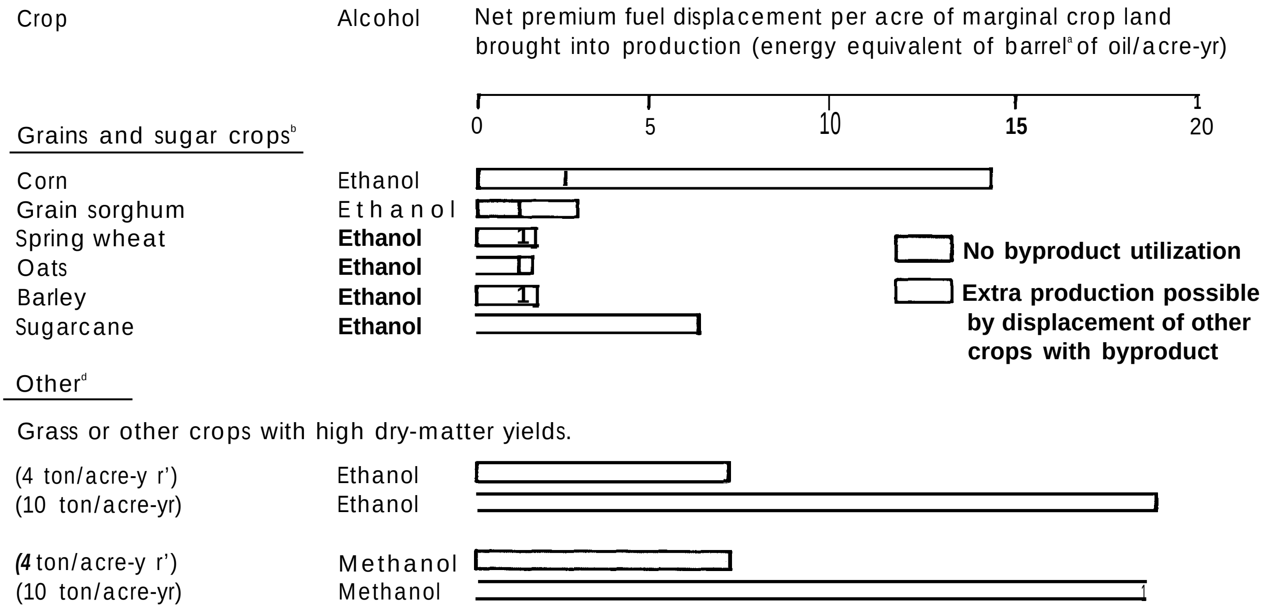
*See Robert Stobaugh and Daniel Yergln, *Energy Futures*, pp 47-55 for a discussion of the real cost as opposed to the market price of Imported oil

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 on 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 cultivation, 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 in 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. In 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

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*See “Energy Balances for Alcohol Fuel” in Vol. II

* *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 cap**ital 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.

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[3] M I Poos and T 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-

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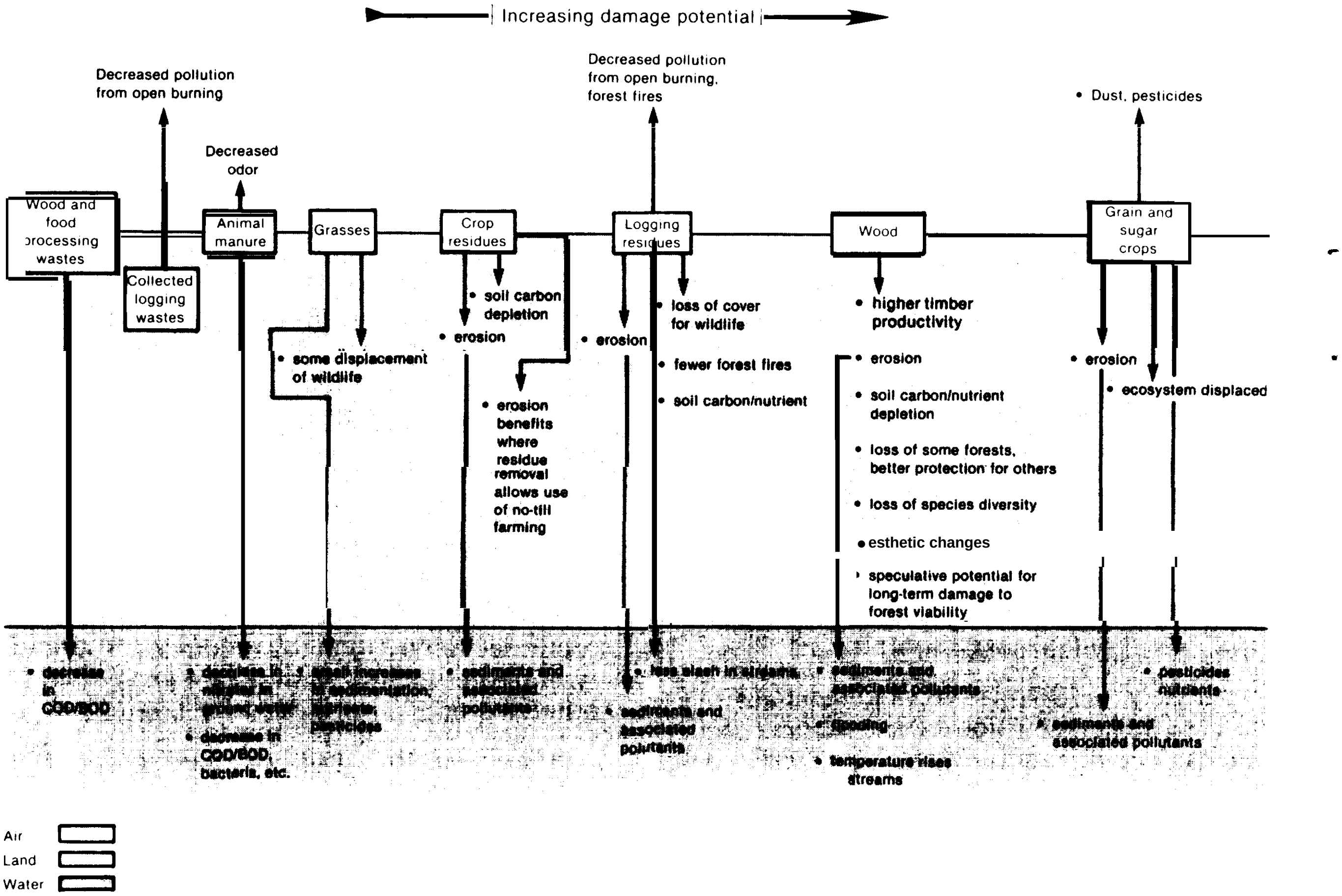
*Assuming that large quantities of existing grasslands are not converted to row crops or other uses.

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 even-age, single-species stands. In 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,

In 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 stillage proves to be impractical for the farmer, then the stillage 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,

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[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 death or permanent injury; and High may 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. In 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 in 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.

In 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