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 opt ions 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 pollut ion 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 "boom-town" 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 minor, 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 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:

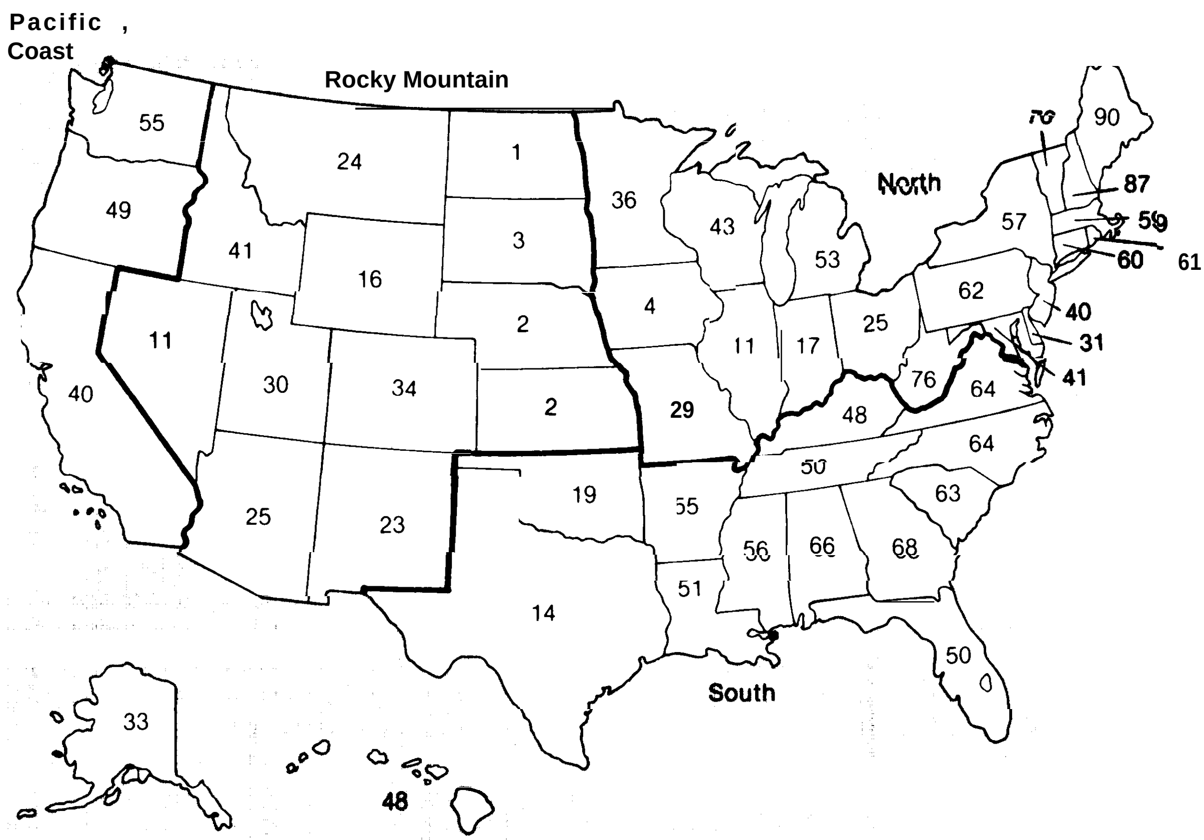
- large increases in intensive management, with shorter times between thinnings, more complete removal of biomass, increased use of improvement cuts, more conversion of low-quality stands;
- not necessarily much change in the total land area subject to logging, but much greater acreage treated *yearly;*
- 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.

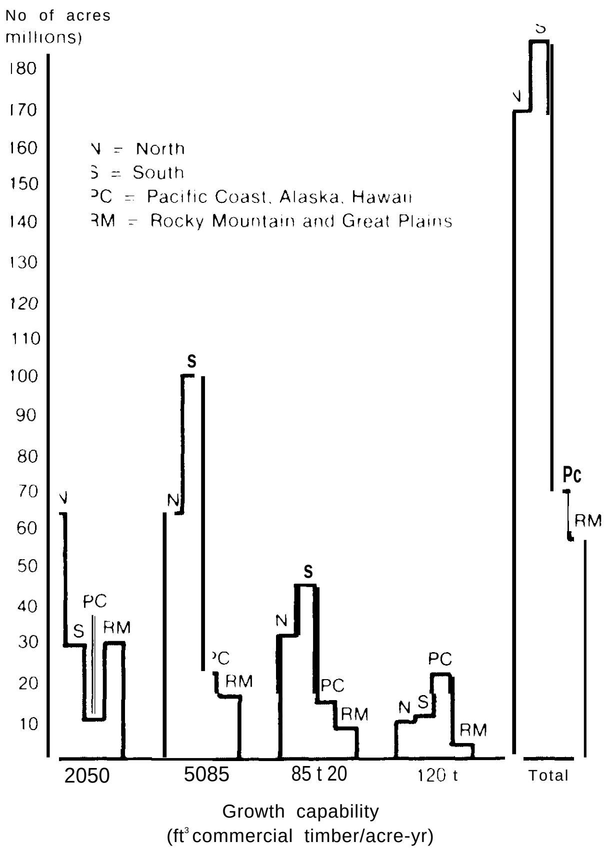
*Commercial forestland occupies 22 percent of the surface area of the 50 States and 66 percent of total forestland.

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

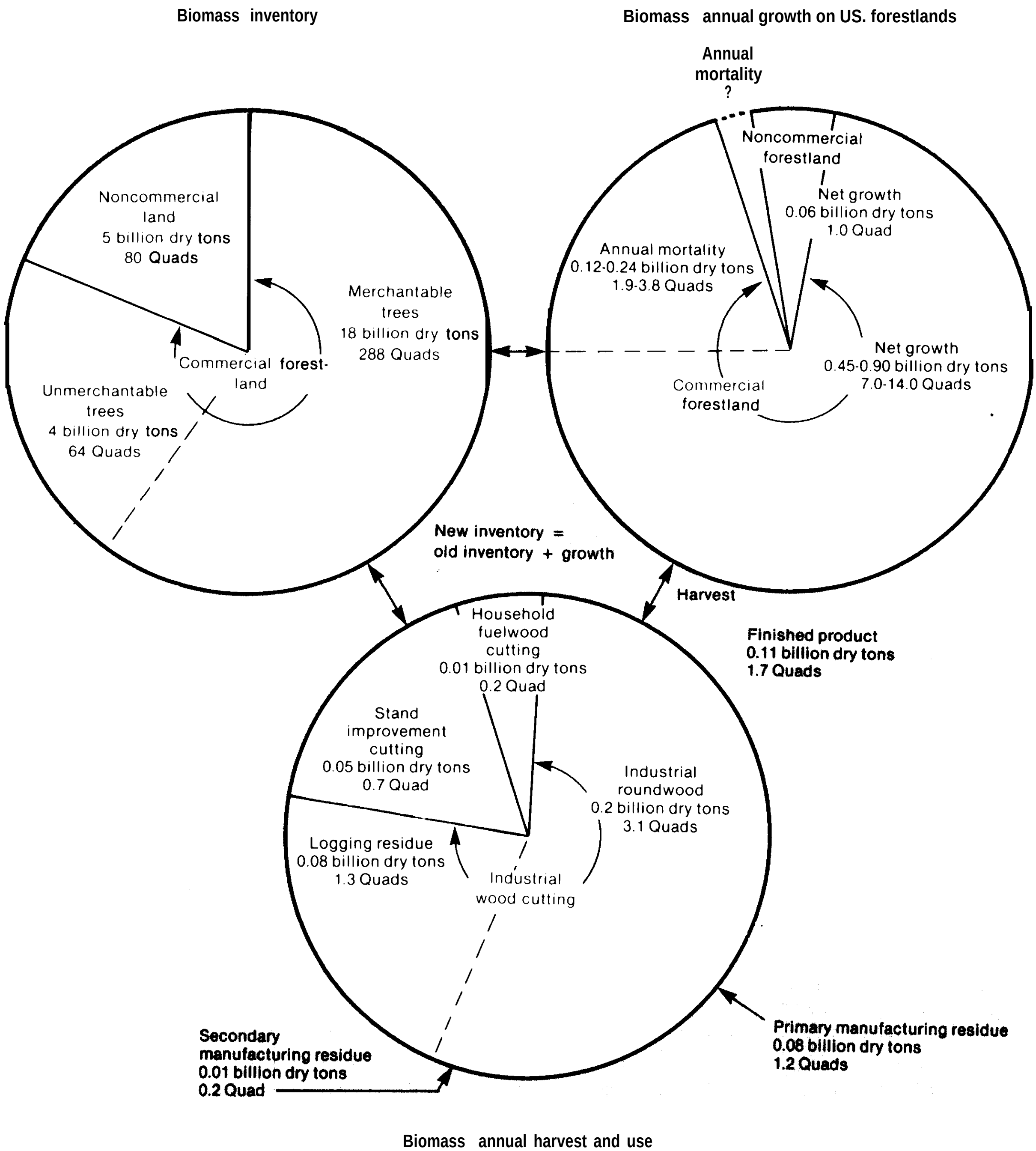
Intensive management schemes produce substantial quantities of residues suitable for energy while increasing the growth of high-quality timber. In other words, increasing the supply of high-quality timber to meet the increased demand for forest products and increasing the supply of fuelwood to meet increased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

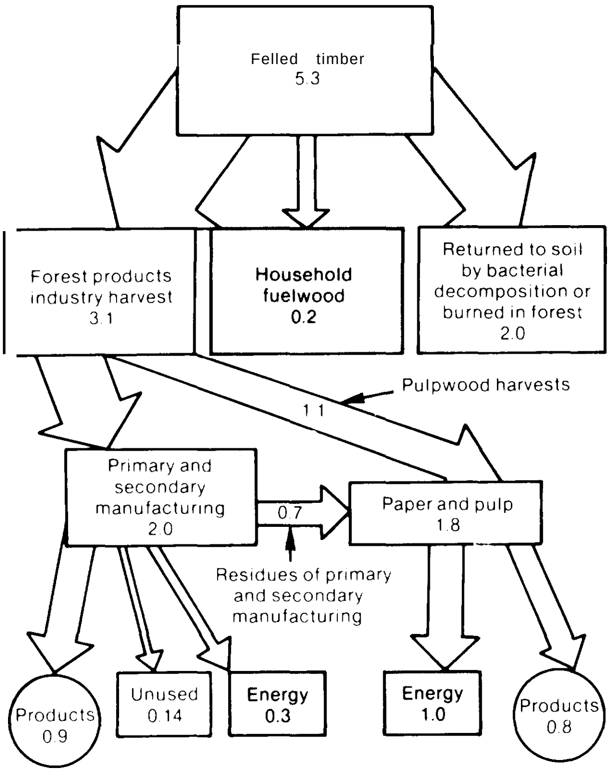
[5]Private communication with Kip Howlett, Georgia Pacific Corp., Atlanta, Ga., 1979

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

Photo credit USDA Bill Marr

Intensive timber management

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

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)

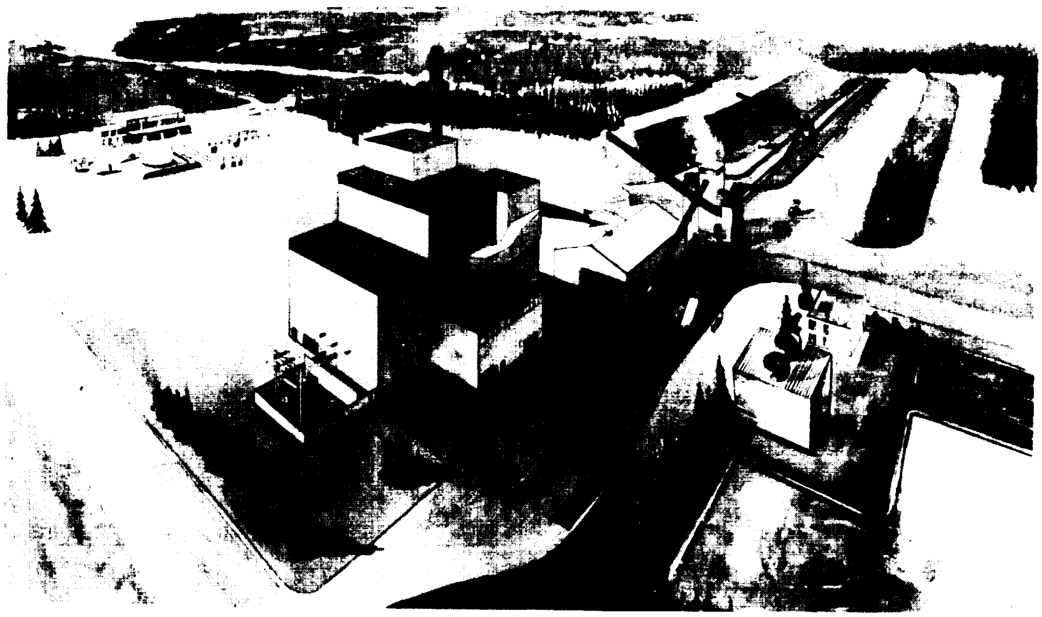
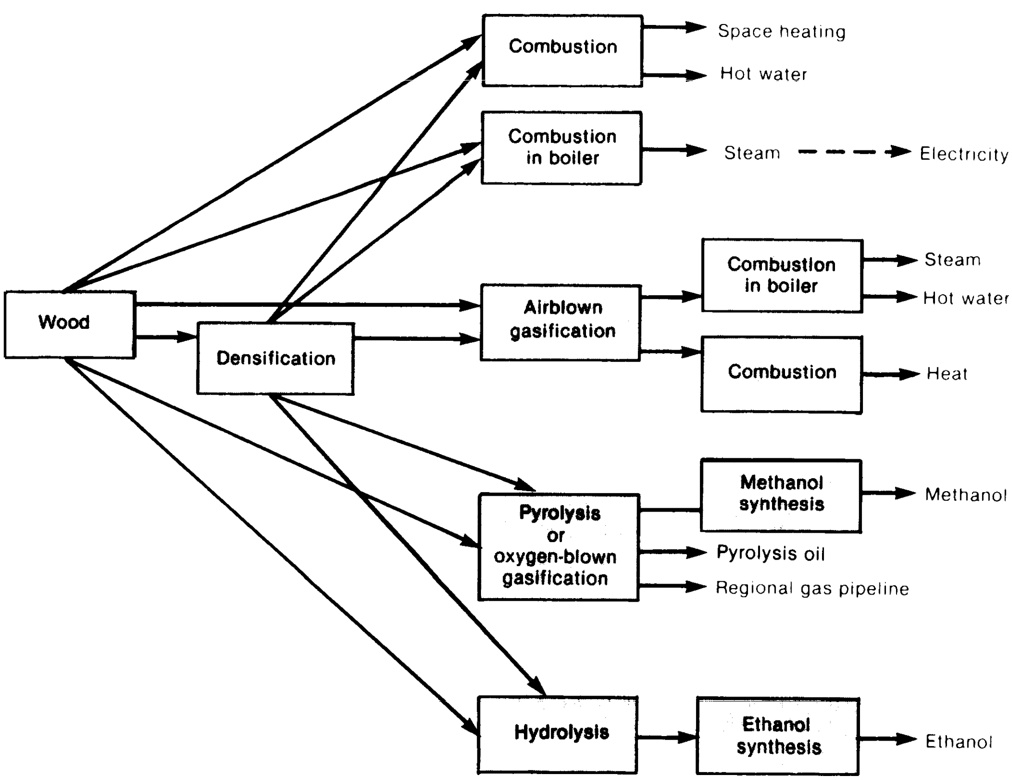


Photo credit Daverman Associates Inc

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.

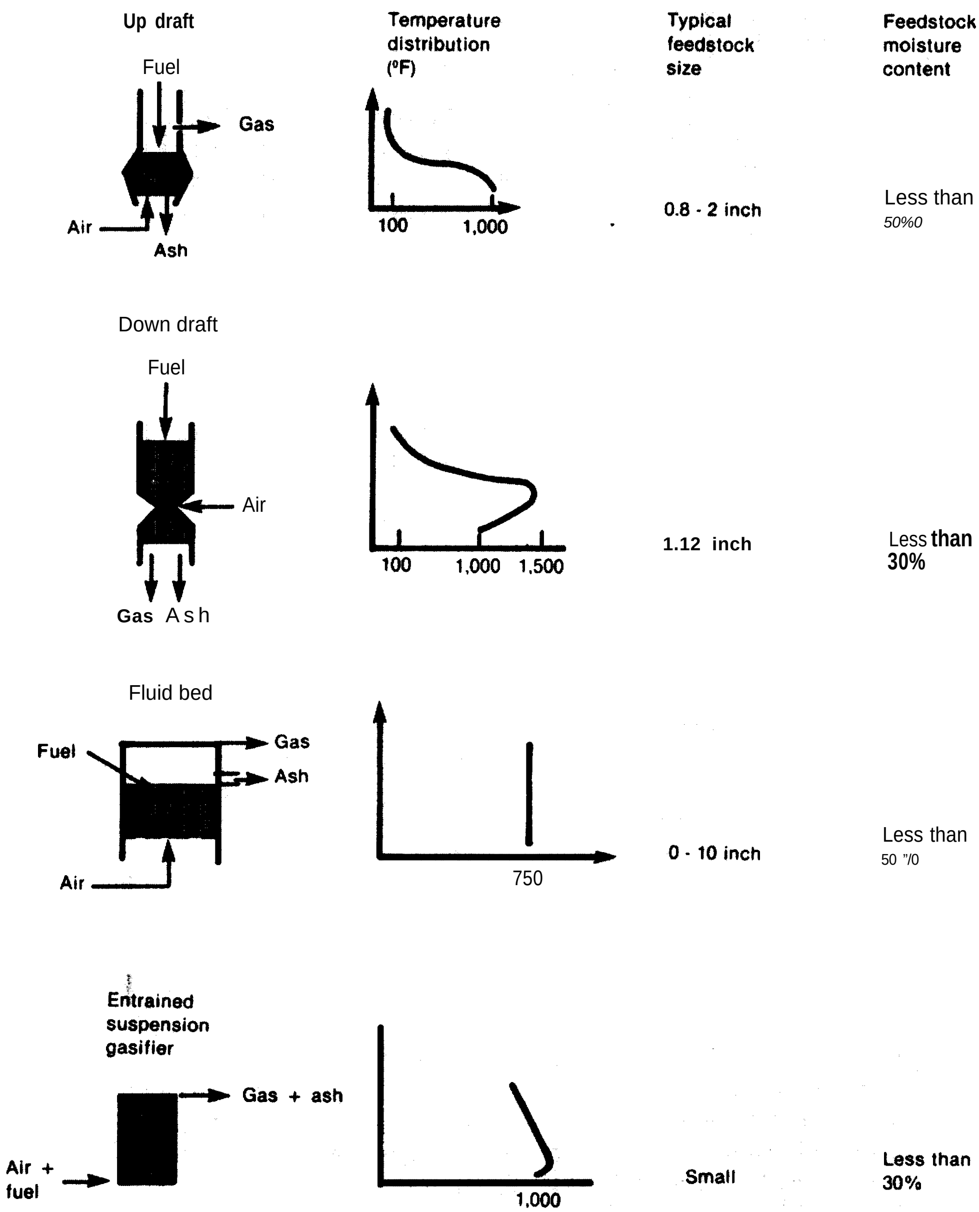
Facilities for converting wood to ethanol and methanol could be constructed immediately although none exists in the United States. The methanol probably would cost about the same (per Btu) as ethanol derived from grains and sugar crops (see "Alcohol Fuels"). The ethanol, however, would be more expensive 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" in vol. II

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.

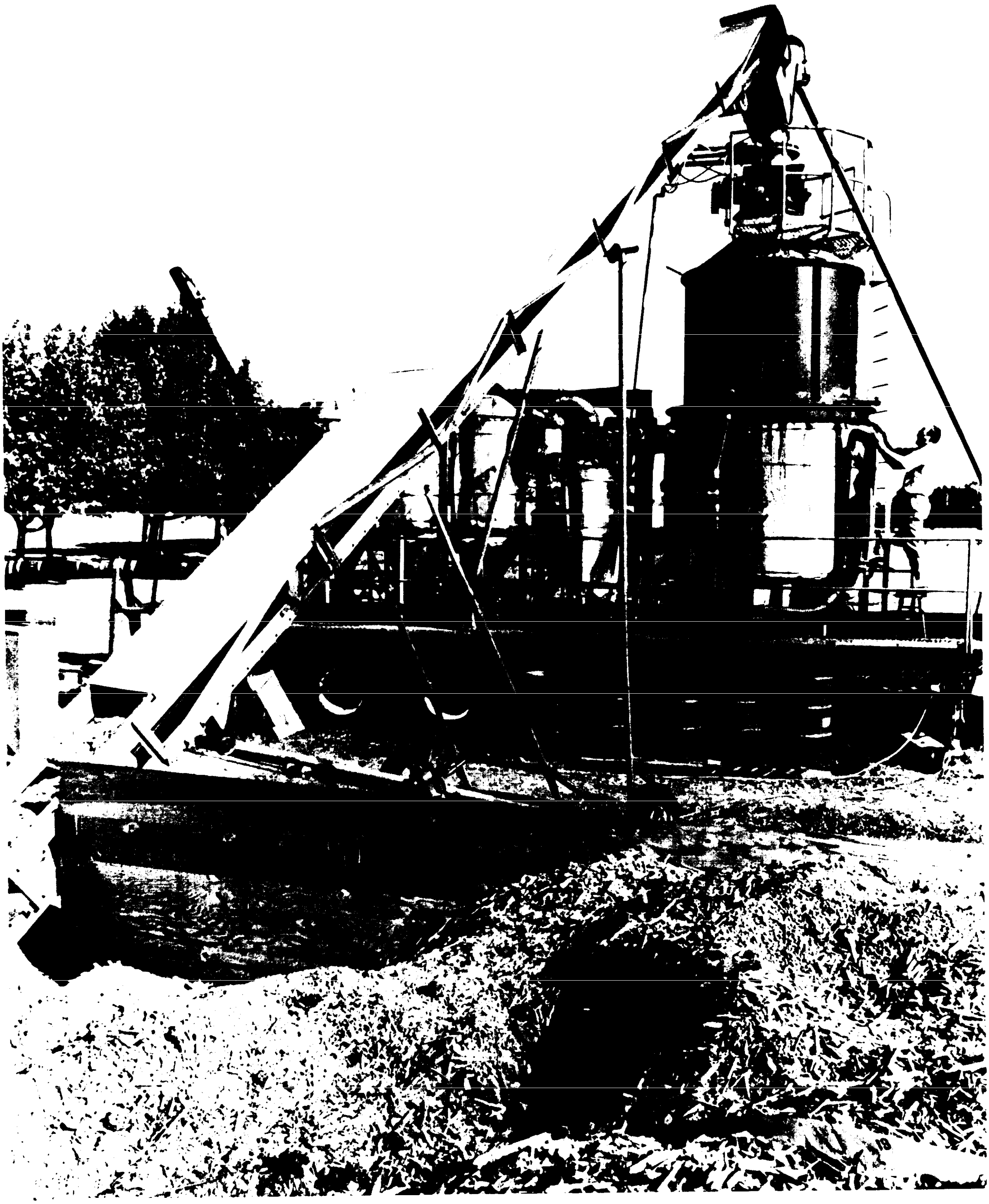


Photo credit Department of Energy Schneider

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

Economics

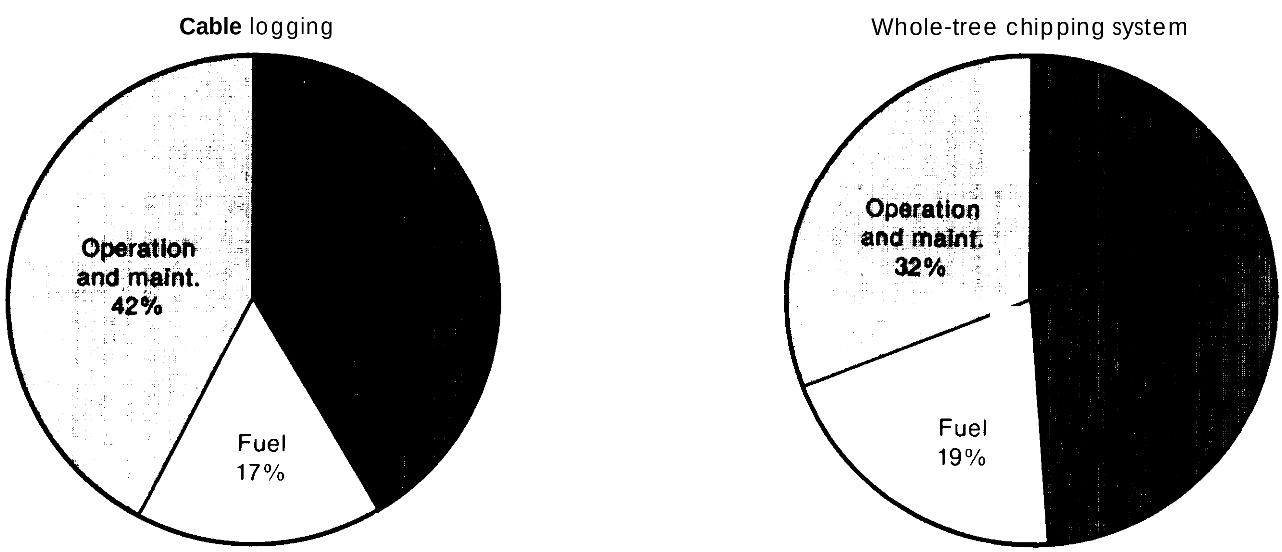
In an effort to reduce their energy costs, energy consumers will bid up the price of fuelwood, taking into account its relative inconvenience, until it is priced comparably with premium fuels. A rising fuelwood price will cover greater harvesting costs and thus make it profitable to use a greater fraction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

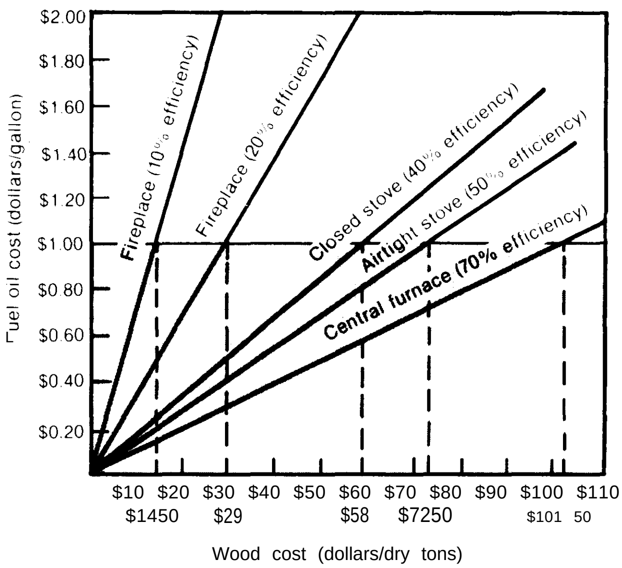
If the long view is not taken, and demand for all wood products rises without proper management, then this very bright picture of synergy at the mill and in the forest will be clouded as available wood resources are stretched to meet all demands. The main problem arises for fuelwood users outside of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

[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

[7]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.

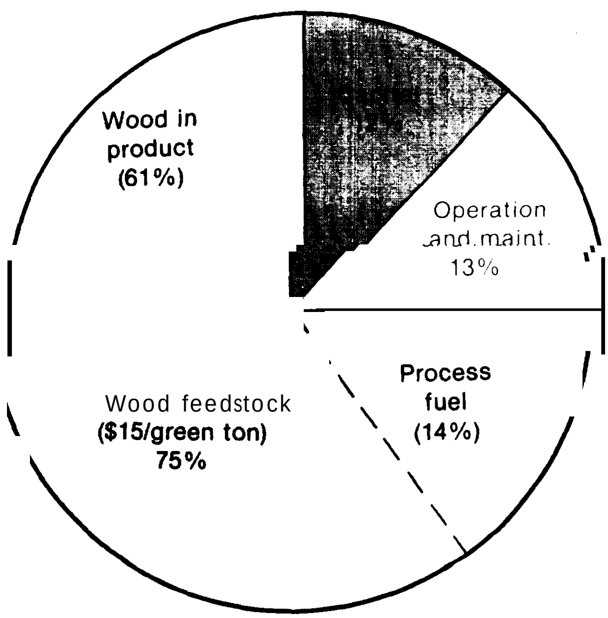
As a rule of thumb, it costs about $0.10/ton-mile to transport wood So, transport of greenwood 200 miles adds **$20** 'ton to the price of wood and about $2.50/million Btu to the fuel cost. In other words, it pays for processors, who would upgrade wood into a preferred fuel, or for final users to locate 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



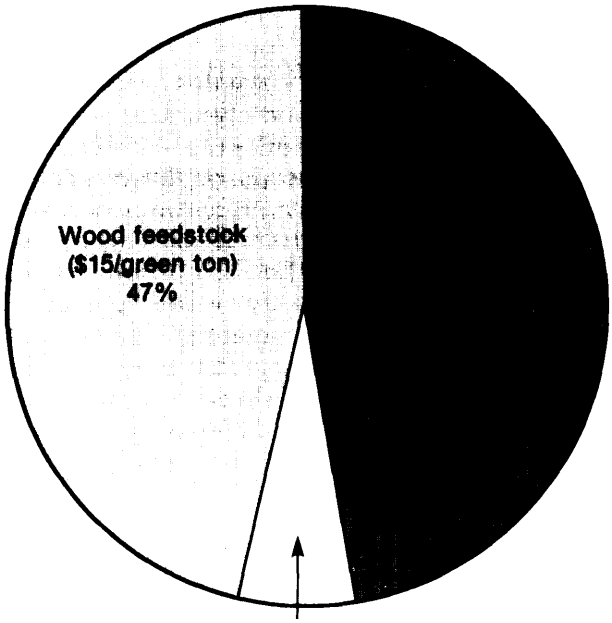
SOURCE Office of Technology Assessment

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.

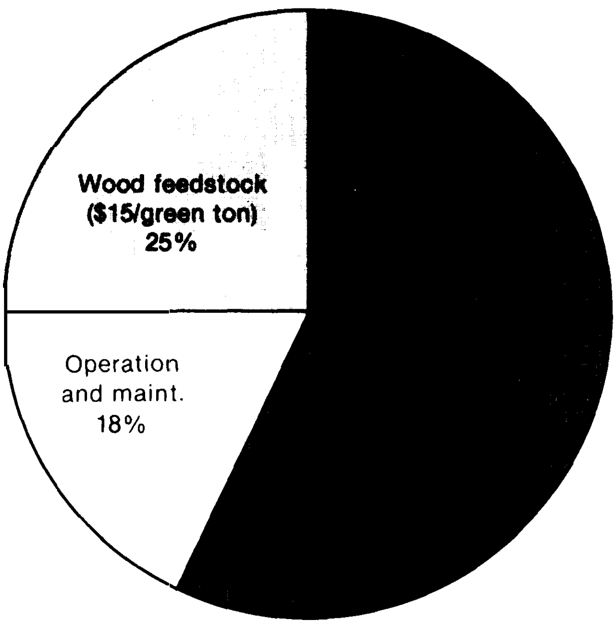
The economic attractiveness of intermediate conversion is also region-specific due to competition with gasifiers and combusters for limited greenwood feedstocks. The latter may require the entire local output of the forests and hence intermediate conversion processes may be priced out of the feedstock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

Figure 20.—Cost Shares of Wood Electricity



SOURCE Office of Technology Assessment

Figure 19. —Cost Shares of Wood Methanol



SOURCE Off Ice 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 also 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

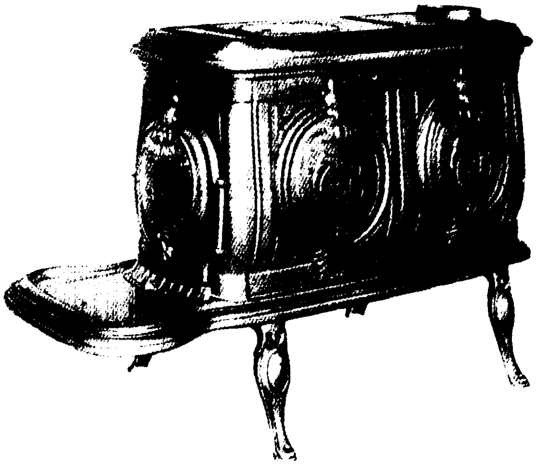
[9] Fuel oil prices from Weekly Petroleum Status Report, Mar. 14, 1980, and Monthly Energy Review, February 1980, Energy Information Administration.

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

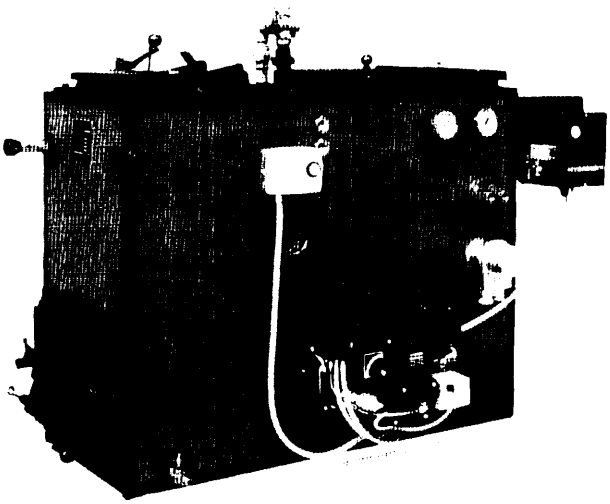
	Total cost	Delivered feed stock cost ($40/dry ton)	Capital cost	Operating cost
Medium-size, industrial user, Greenwood use: 250 dry ton/d; Load factor: 90%; Energy efficiency: 85°/0	$3.60	$2.95	$0.40	$0.25
Smaller, commercial user Greenwood use: 30 dry ton/d; Load factor: 25%; Energy efficiency: 700/0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

SOURCE Office 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 noncommercial 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 "char acter,"
- 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 m i l l ion 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:

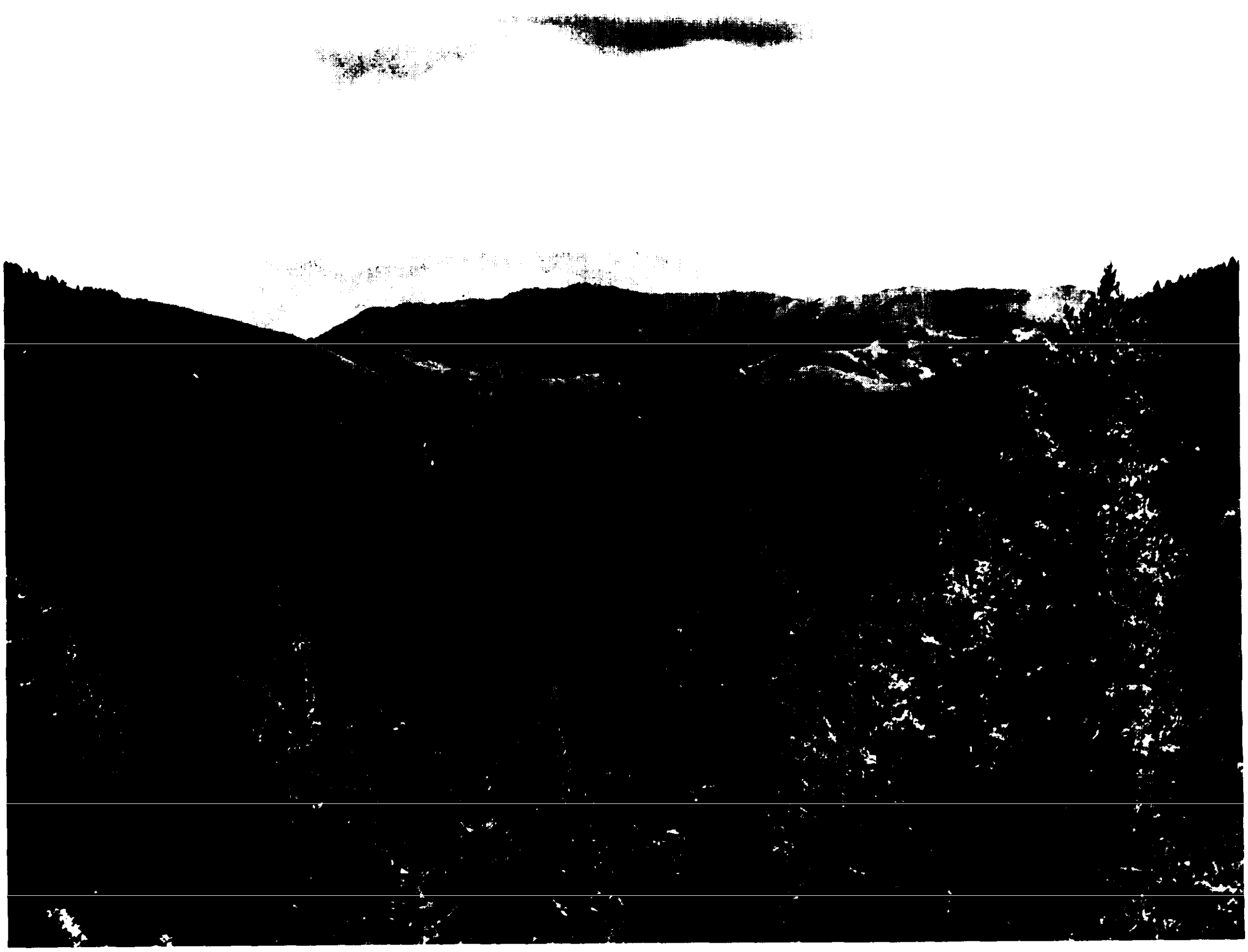
- Major effects on the availability of high-quality timber probably would not occur for a number of years. Some additional high-quality wood might be available immediately from stand conversions and harvest of noncommercial timber, and some in about 20 years from timber growth in stands that required 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.

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 roadbuilding (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

*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.

*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

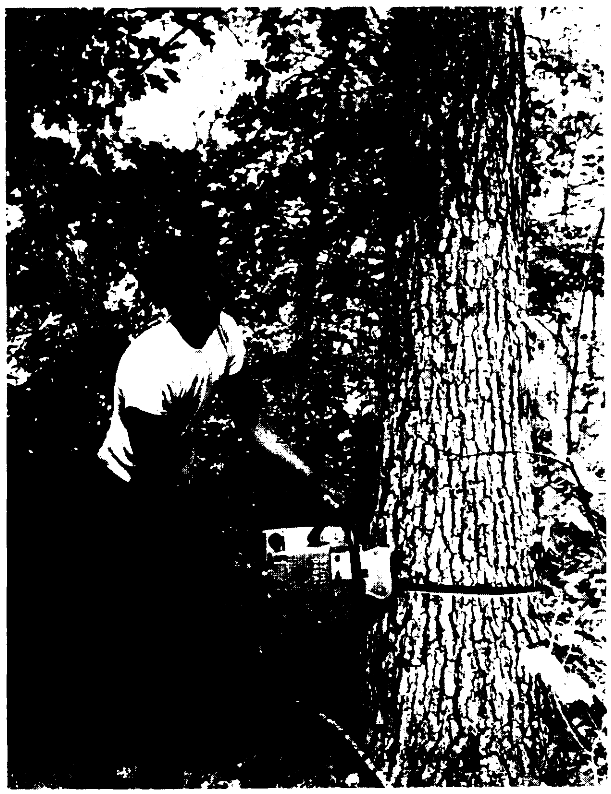


Photo credit USDA. Bill Marr

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-f i red 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. I n 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 1 977 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

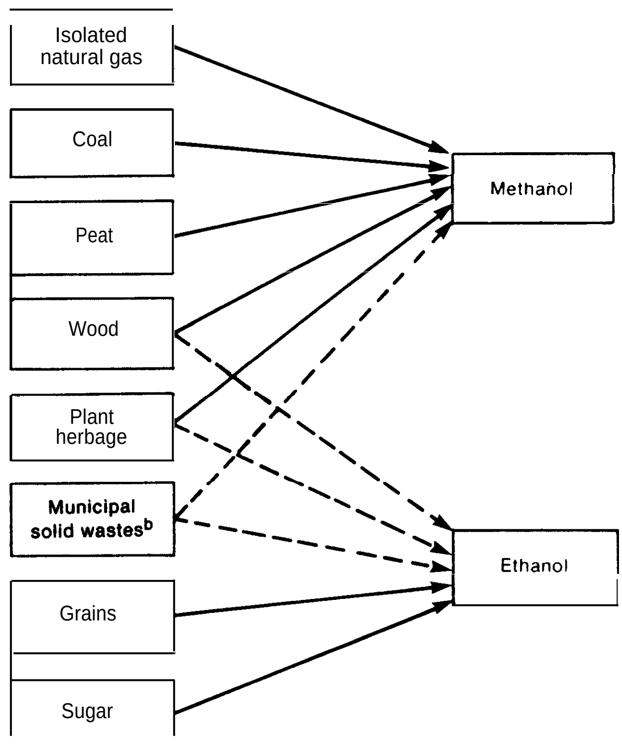
In early 1980, the United States consumed 600 million to 900 million gal/yr of gasohol, a mixture of gasoline and ethanol. (This corresponds to 60 million to 90 million gal/yr of ethanol.) Mixtures of methanol and gasoline may also be feasible or the alcohols could serve as standalone fuels for many 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

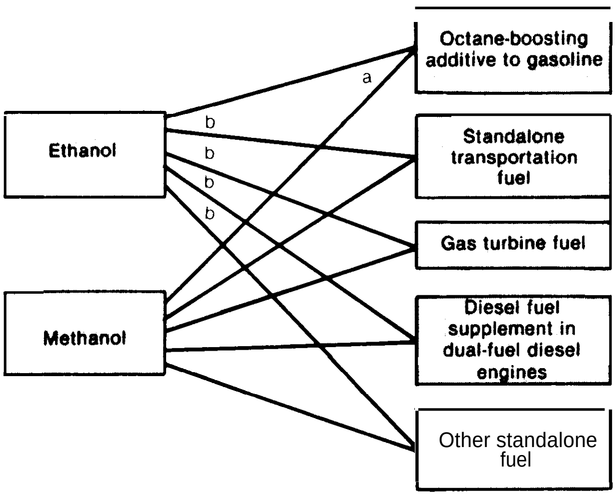
[b] Plastics in municipal solid waste may Interfere with methanol synthesis Consequently ethanol synthesis may prove 10 be the less expensive liquid fuel from this source

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. Meekhot, W. E. Tyner, and F. D. Holland, "Agricultural Policy and Gasohol," Purdue University, May 1979.

Figure 22. —Uses of Alcohol Fuels

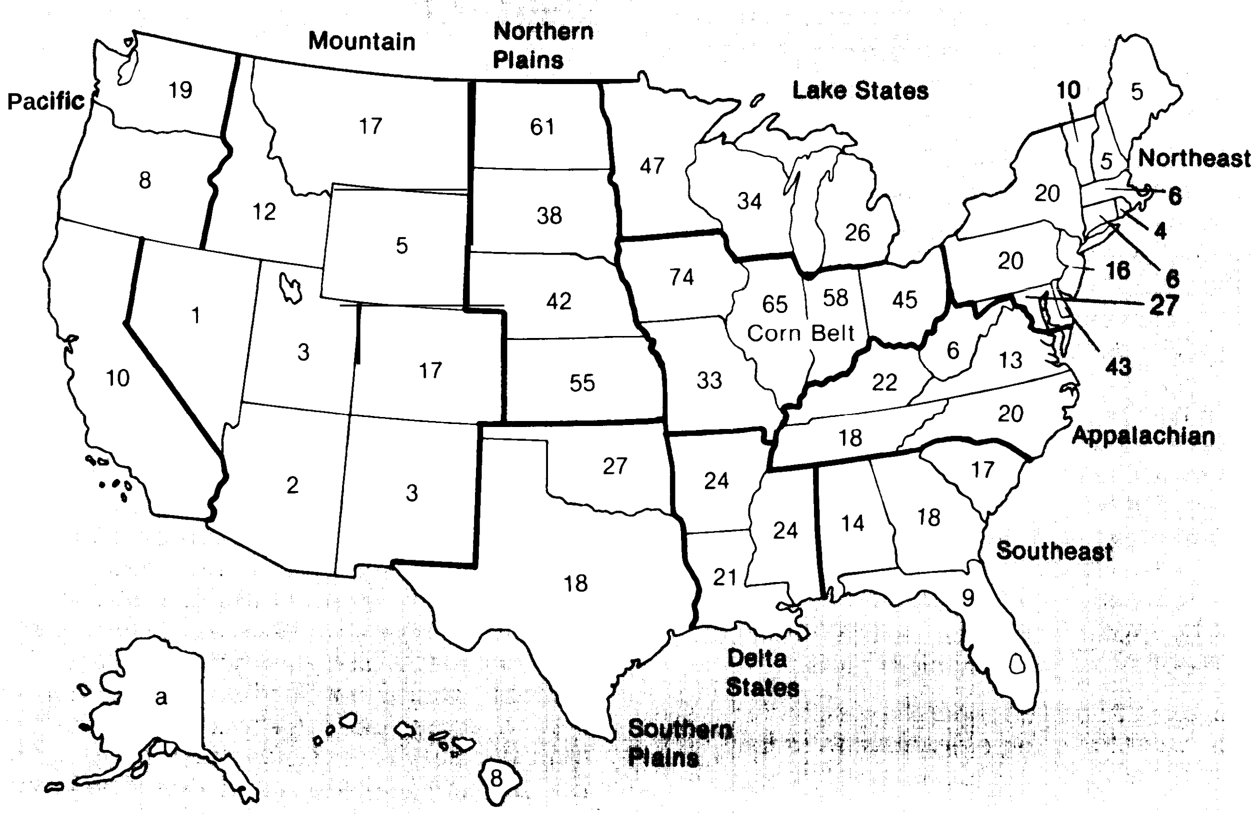


[a] May need other additives
[b] Probably not a preferred use if derived from grains and sugar crops
SOURCE Office of Technology Assessment

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.

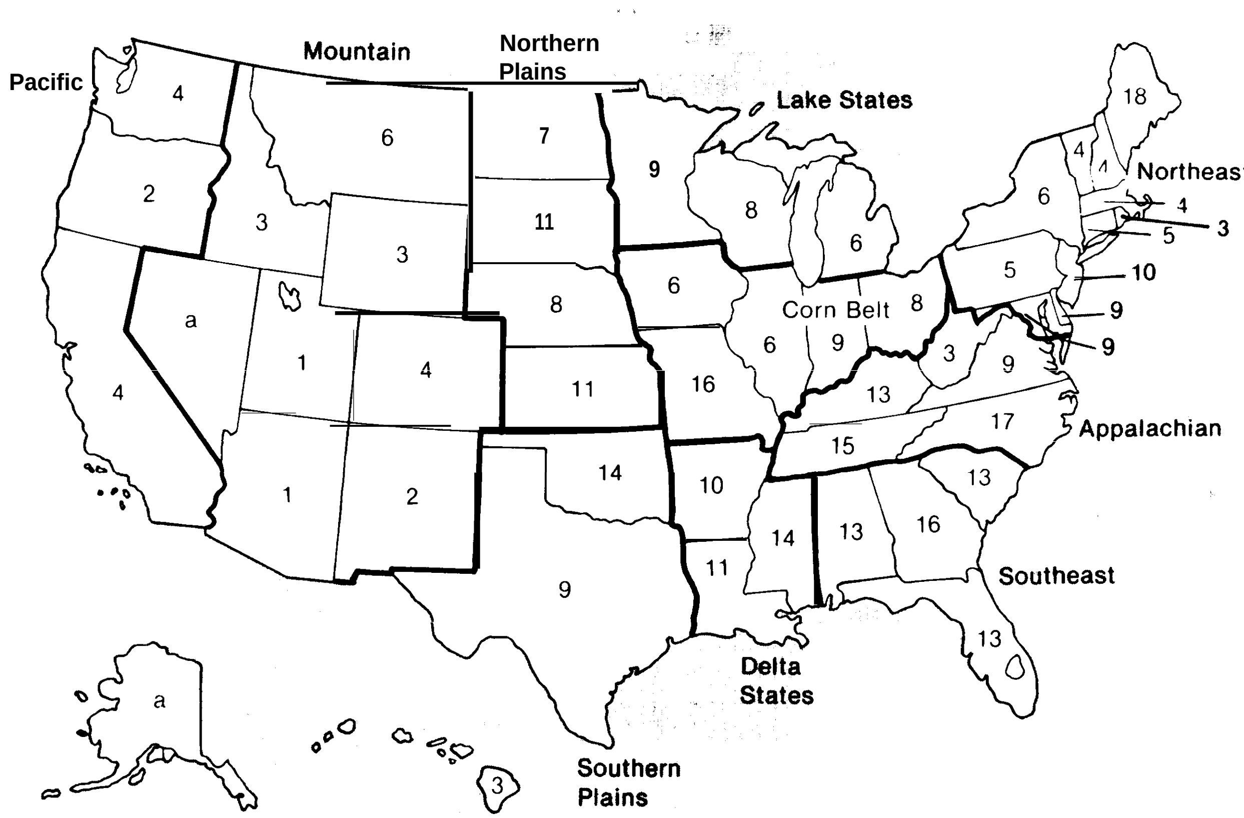
Although actual market penetration is difficult to predict, converting 4 Quads/yr of wood, grasses, and crop residues to methanol would yield about *30* billion gal/yr. Assuming that **7 billion** gal are used as octane-boosting additives to gasoline and that the remaining 23 billion gal are used as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

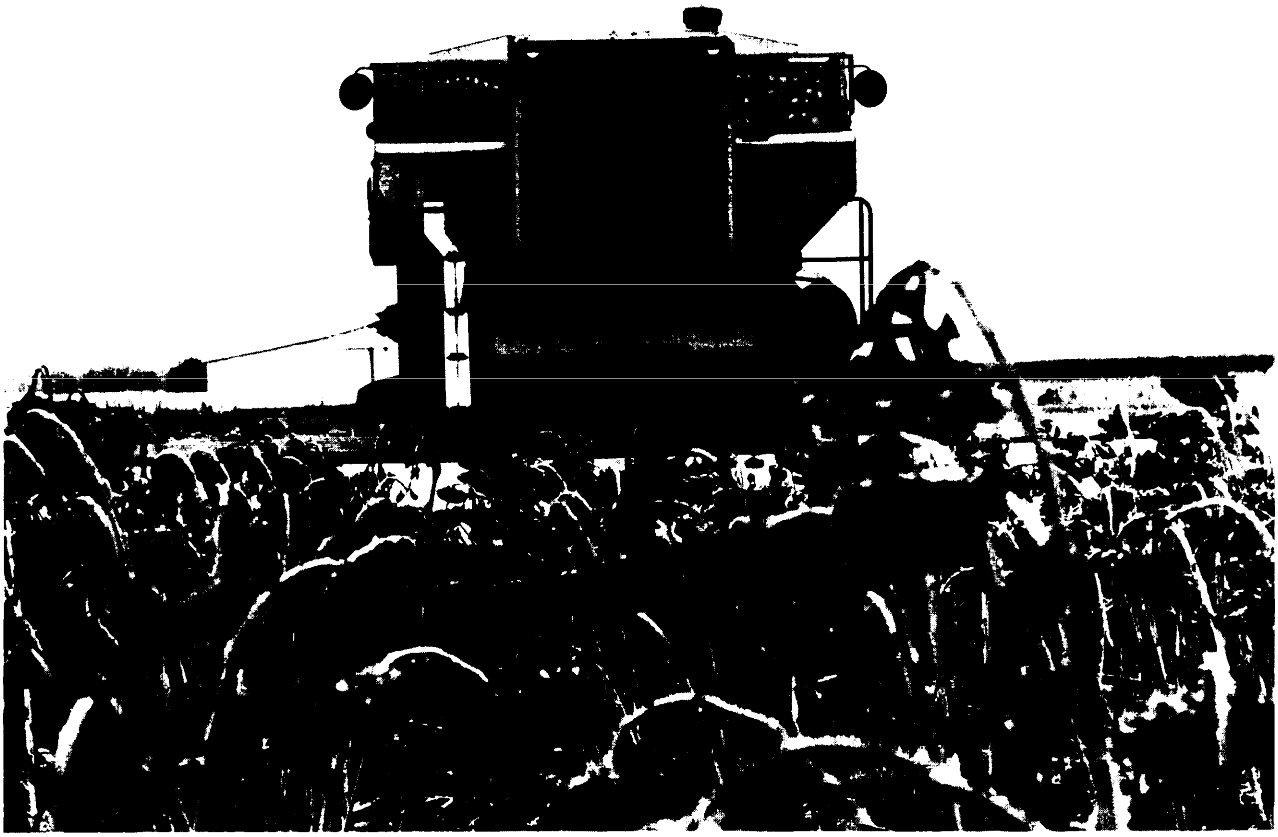


Photo credit USDA, Lowell Georgia

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.

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

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

*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 dependin g 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.

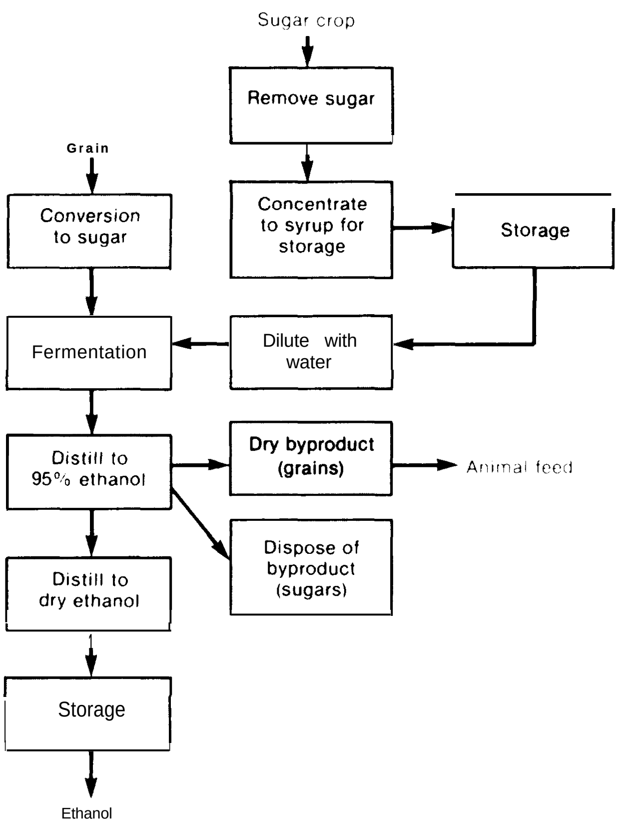
Ethanol

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)

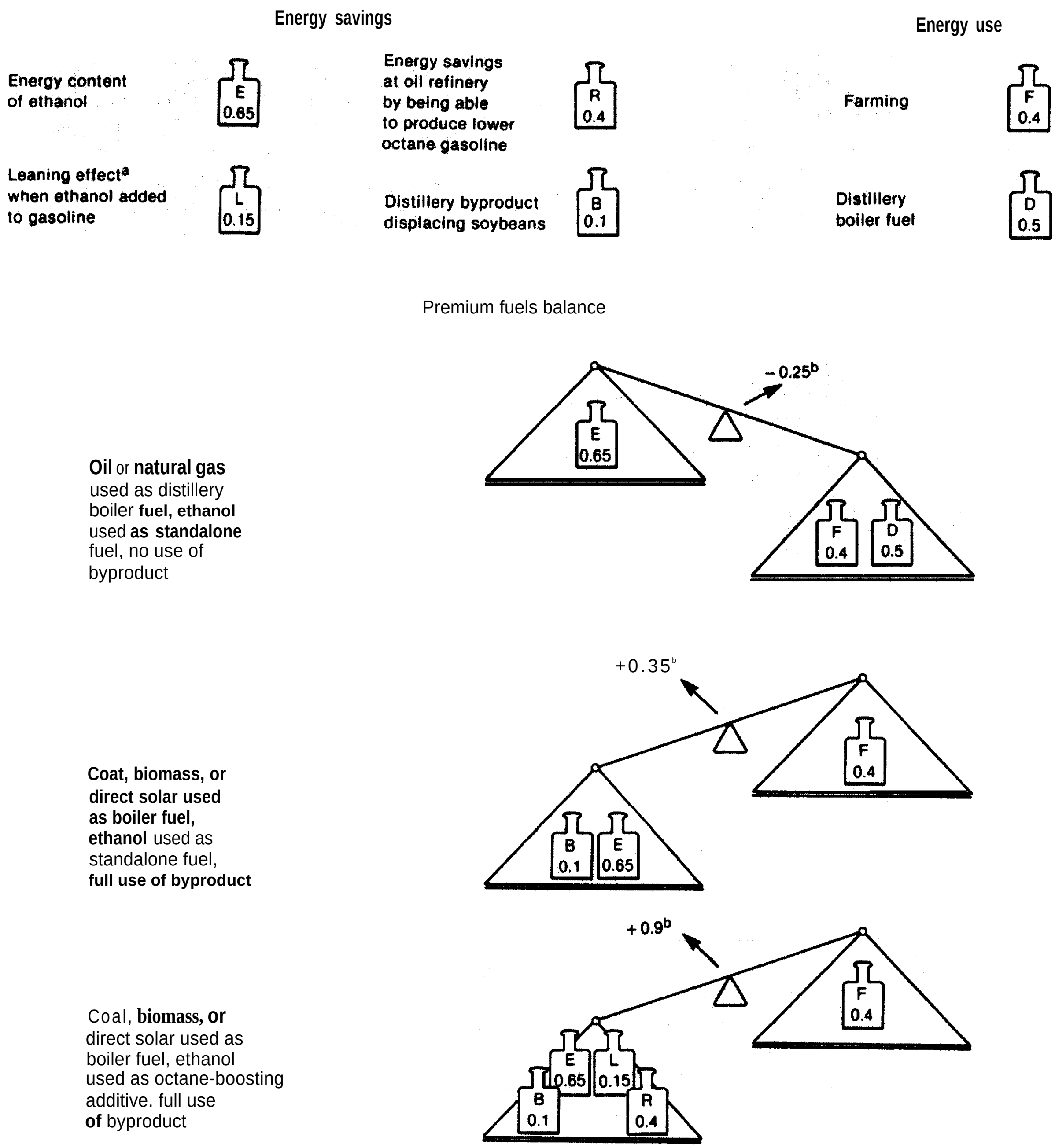
If used as an octane-boosting additive and distilled without use of premium fuels, each gallon of ethanol can displace up to about O *9* gal of gasoline. (This is a displacement of premium fuel only,) In contrast, if ethanol distilleries are fueled with oil and distributors do not take advantage of ethanol 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 torm a "regular grade" gasohol, or it the ethanol is added to regular unleaded gasoline to torm a premium-grade tuel *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.

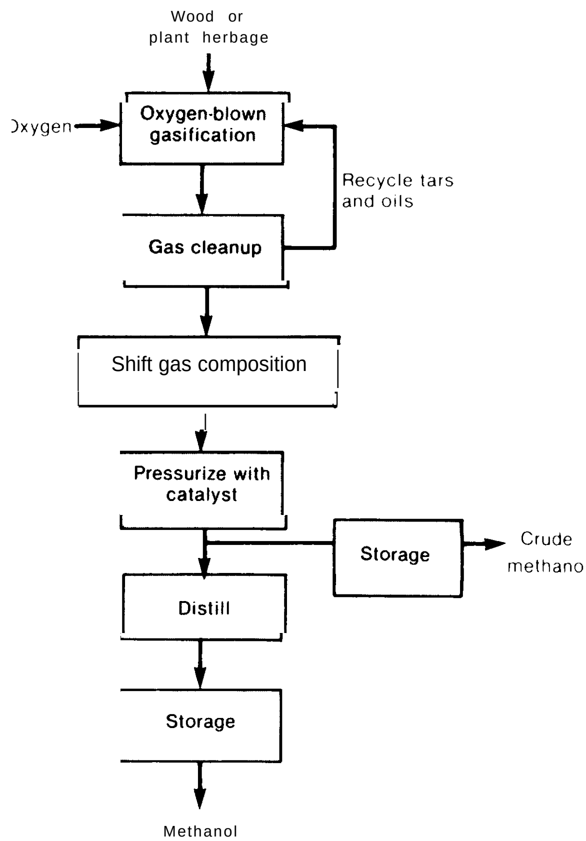
Methanol

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.

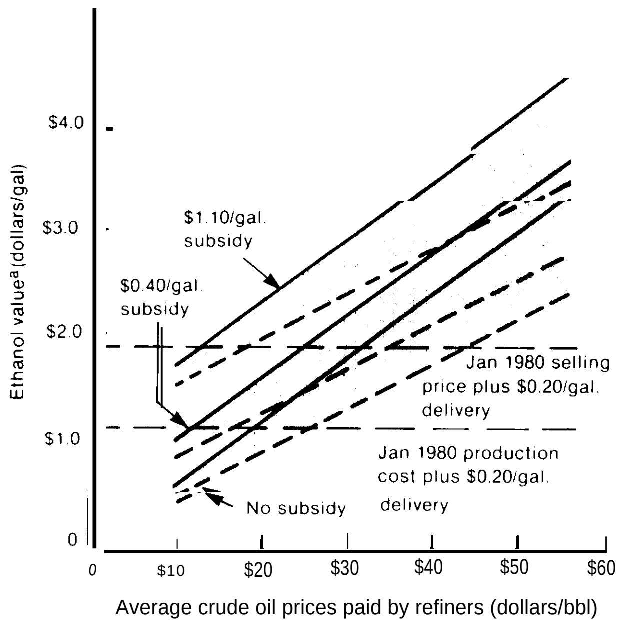
2. A **gas station is the potential buyer. Assume that the current markup the station obtains on gasohol will not change as the gasohol market matures.** –Gasoline retailers bought regular unleaded gasoline for about $0.70/gal in July 1979 **and sold gasohol** for a rough average of $0.03/gal more than 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

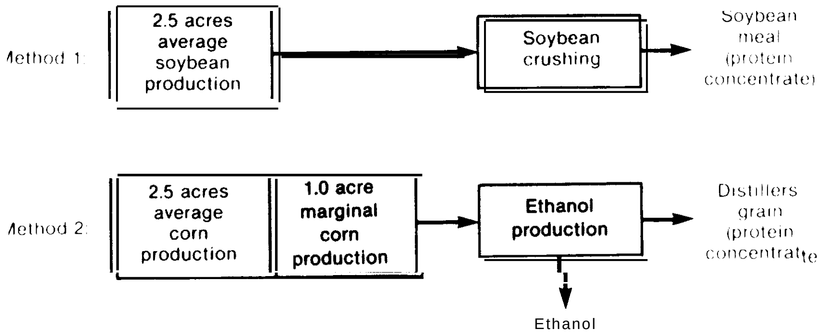
* Note that individual buyers will make decisions based on *actual* rather than *average* costs and benefits of ethanol. Thus, calling ethanol "competitive" here means only that profitable markets will exist. It does *not* mean that all possible buyers will actually want to buy ethanol, or that *all*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

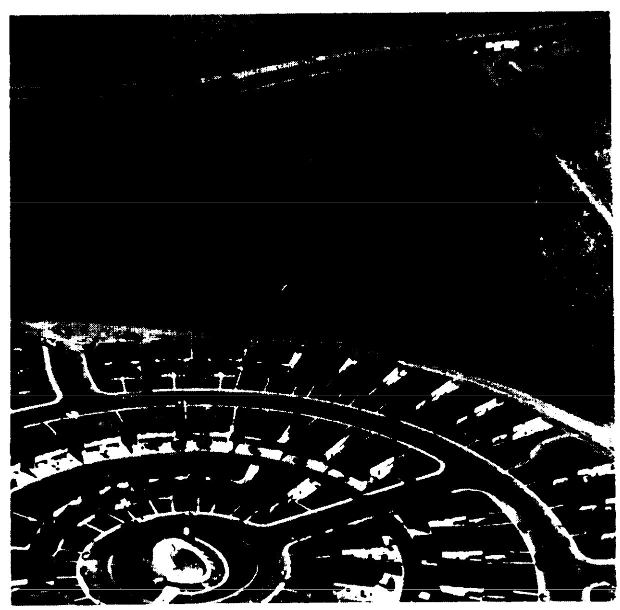
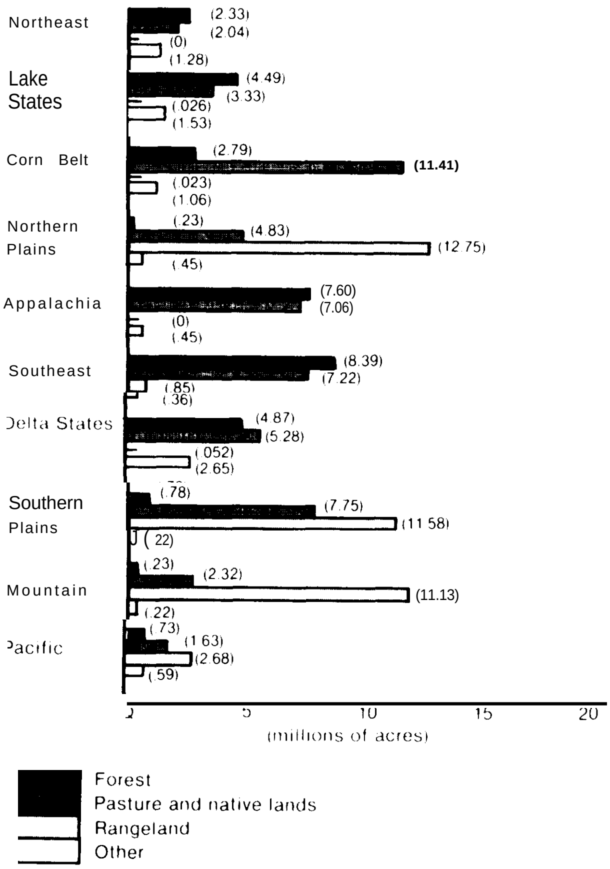


Photo credit USDA, J Clark

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 Fuel Use?" 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

*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

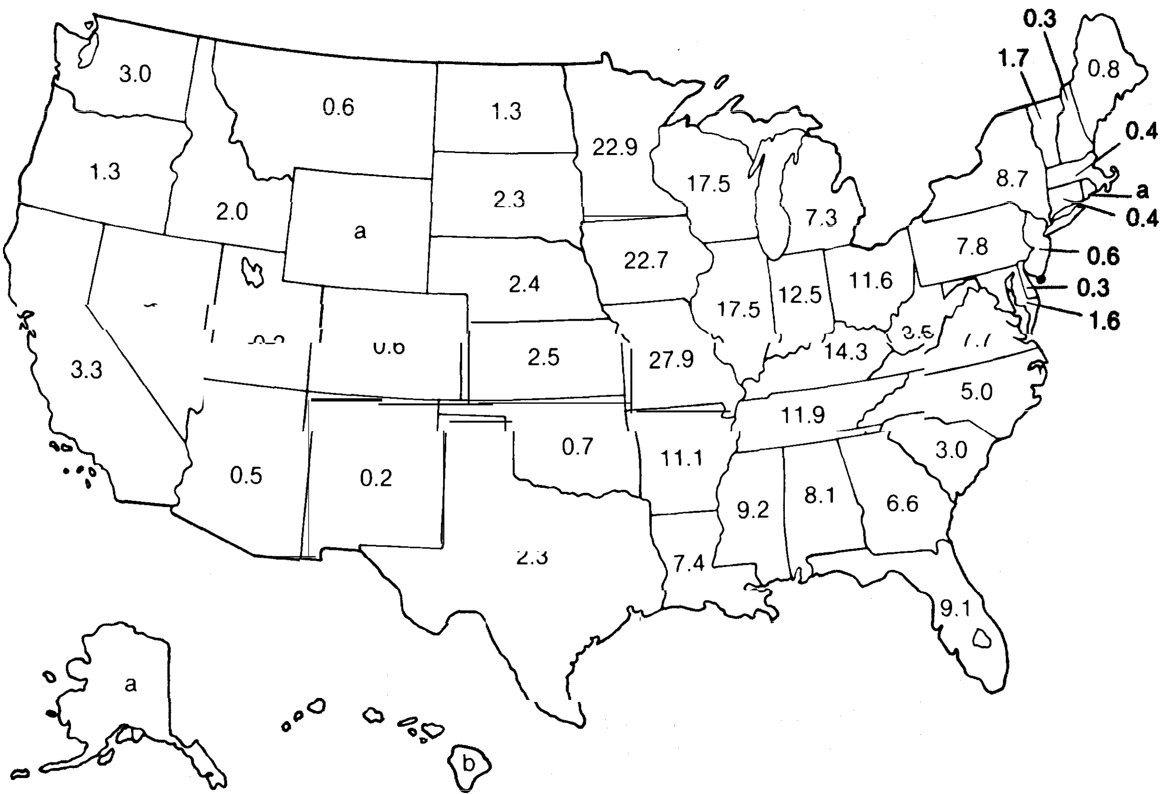
Crop residues and grass and legume herbage are discussed together because they have similar physical and chemical properties, they both occur in the farming regions of the United States, and farmers can harvest them for energy and additional income. For the sake of simplicity, the use of "grass" or "lignocellulose 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 0.1

[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

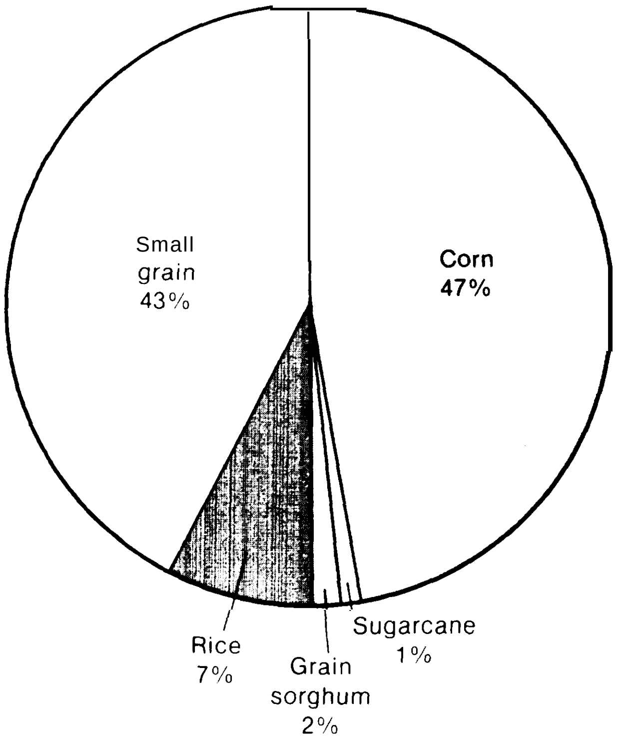
SOURCE. Office of Technology Assessment.

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)	Quantity (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.

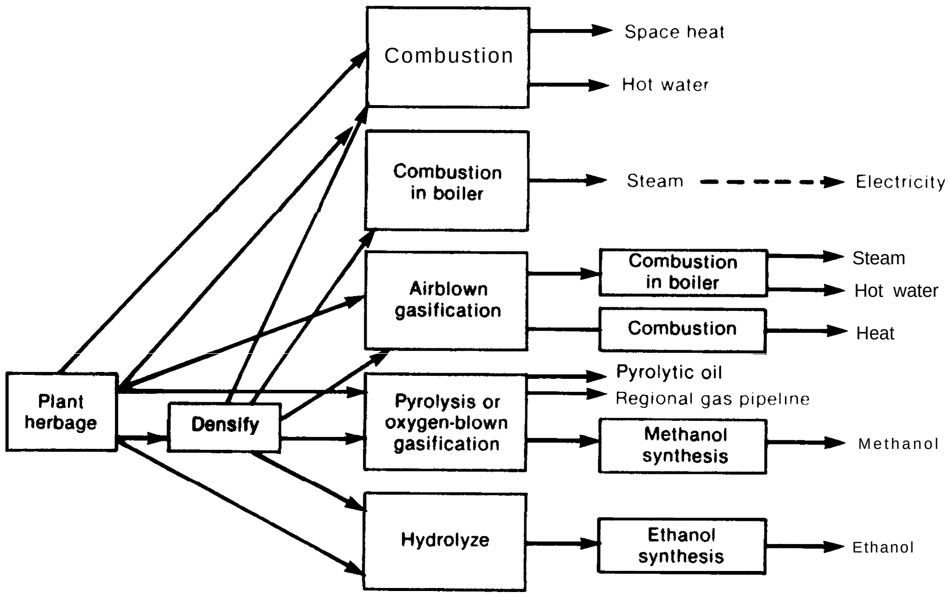
Grasses and residues also can be gasified (by partial or incomplete combustion) in intermediate-Btu gasifiers currently under development. The resultant fuel gas could be burned in retrofitted oil- or natural gas-fired boilers. Users could then revert to oil or natural gas without additional cost if 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_2. (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_2) 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.

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

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

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.) I n 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. ” 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

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[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	—

aAssumes 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 Utility*, final report to the Ozarks Regional Commission (Kansas State University Center for Energy Studies No. 41, 1977).

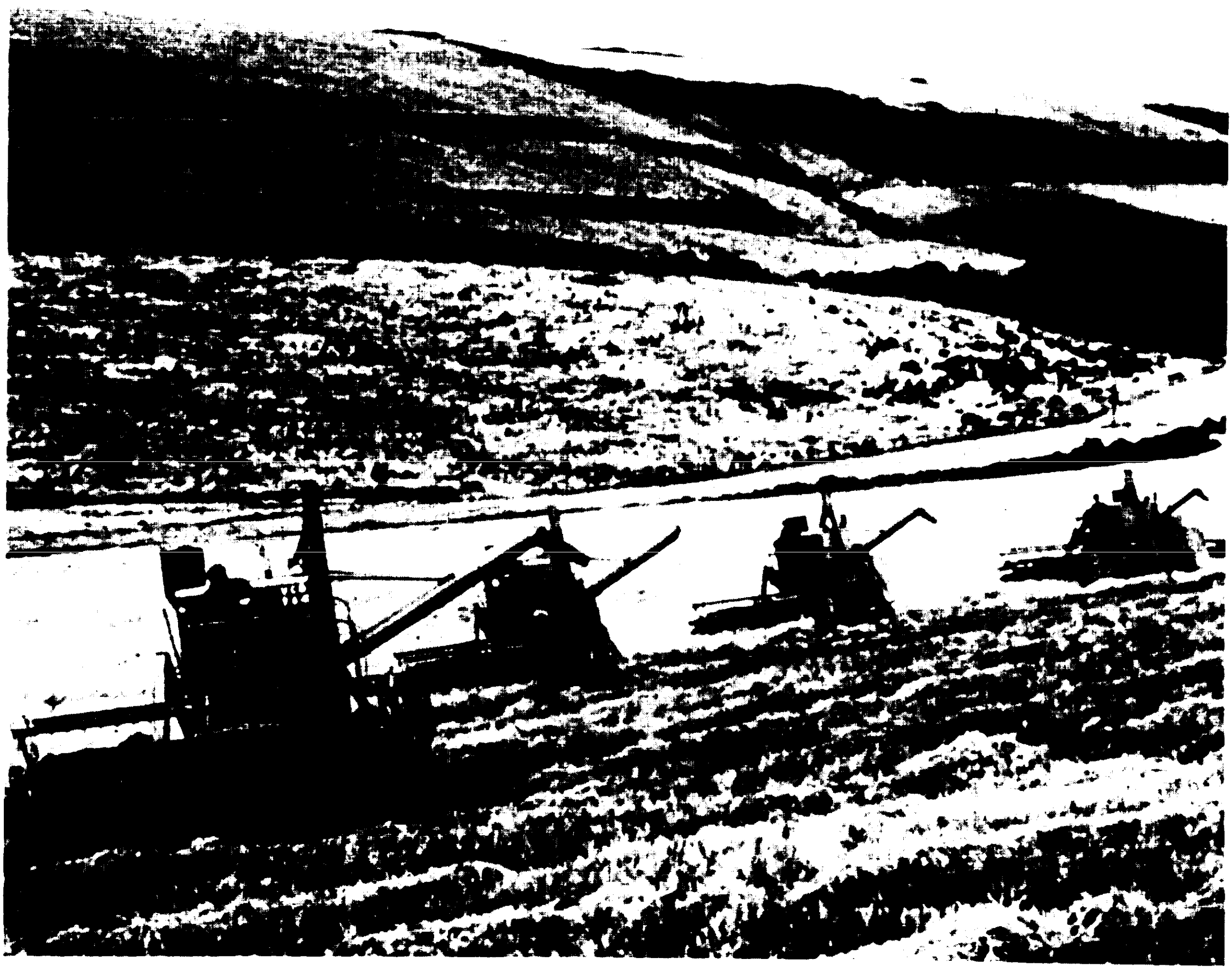


Photo credit: Department of Energy

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.

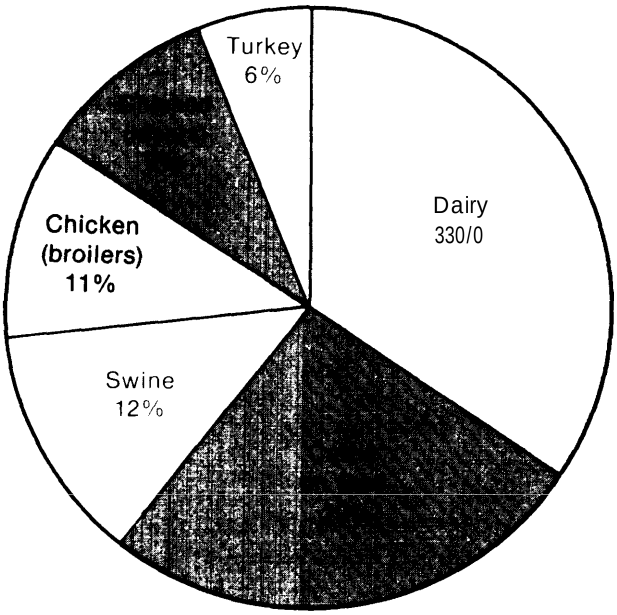
Table 14.—Characteristics of Various Substrates for Anaerobic Digestion

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. *

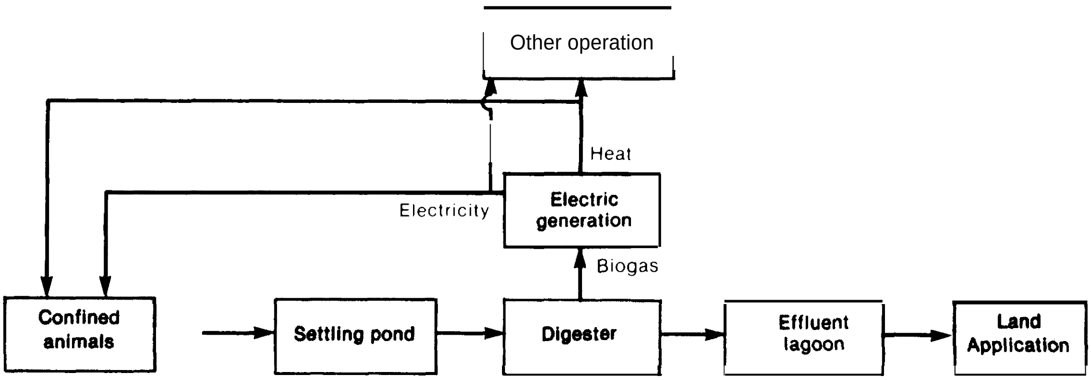
In a common digester system (figure 35), a settling pond is used to store the manure prior to digestion. The digester consists of a long tank into which the manure is fed from one end. After several weeks, the digested manure exits at the other end and is stored in an effluent lagoon. Gas exits from 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 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] R. E. Cole et al., "A Survey of Worcester County, Massachusetts, Dairy Farmers With Respect to Their Potential for Methane Generation," *Science Technology Review*, September 1970, 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 I imitations 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)

Fuel	Demand sectors: Residential/ commercial	Industrial	Transportation	Electricity	Supply: 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.

[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 197\ residential and commercial energy use data by Oak Ridge National Lab (ORNL/CON-13 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.

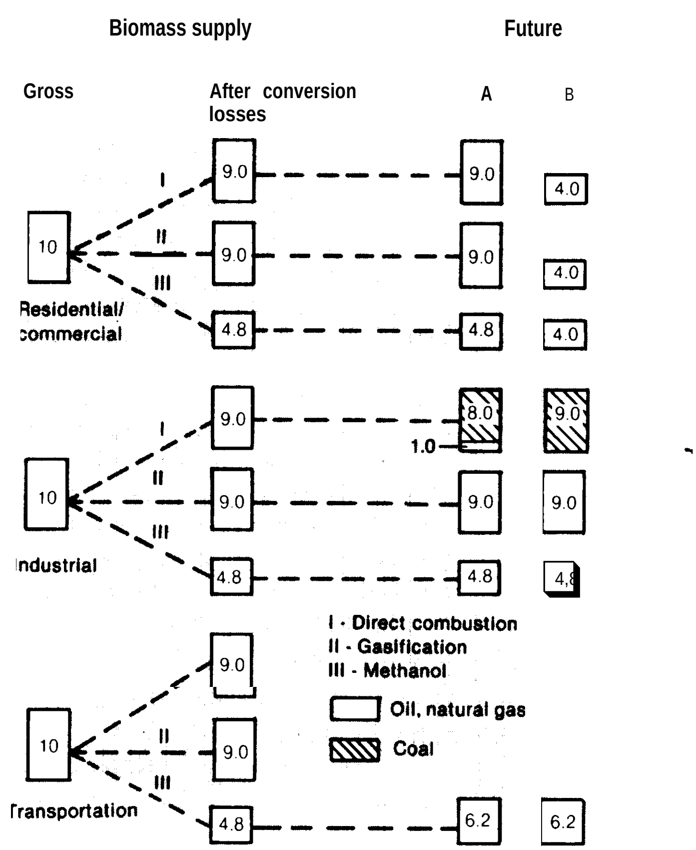
ment modification would also be necessary to account for the different combustion properties of methanol compared to fuel oil, although these should be minor. In this connection, the different combustion efficiencies between methanol and conventional fuels would have to be considered in determining final 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)



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