World Resource Review Vol. 3 No. 4

LIQUID FUELS FROM WOOD - ETHANOL, METHANOL, DIESEL

John I. Zerbe
Program Manager, Energy Research, Development, and Application
Forest Products Laboratory
One Gifford Pinchot Drive
Madison, WI 53705-2398

Processes for making liquid fuels from wood have been understood and available for longer than such fuels have been used in vehicles for transportation. But, the economics of liquid fuels from wood as compared to engine fuels from fossil fuels have been Unfavorable. For the last 75 years there has been research at the Forest Products Laboratory and elsewhere to improve these unfavorable economics. This paper reviews progress that has been made, and the suitability of different types of liquid fuels from wood in today's unsettled global economic and international trade situation. Estimates of the available domestic supply and cost of wood for use in production of liquid fuels are also given.

The three approaches that are most promising for making liquid fuels from wood are methanol, ethanol, and diesel fuel, but other liquid fuels from wood are possible. Methanol was the first fuel from wood and is often called wood alcohol. Ethanol has been the focus of research at the Forest Products Laboratory. There has been little attention to diesel fuel from wood, although there has been some research on production from synthesis gas and through utilization of extratives in wood.

The United States accounts for about 23 percent of the world's emissions of carbon dioxide. Of the U.S. sources of carbon dioxide in 1987, electric power accounted for 35 percent, transportation 30 percent, industry 24 percent, and residences 11 percent. Obviously, if we're to do our share in reducing carbon dioxide emissions, we should consider making a change in using more non-fossil fuels. The transportation industry is based almost totally on the use of liquid fossil fuels, therefore wc should consider taking measures to reduce this consumption.

Liquid fuels that could be suitable for use in transportation vehicles have been made from wood for a long time. Methanol was commonly called wood alcohol, and this term is still used. Braconnot in 1819 discovered that cellulose which is the largest wood component could be dissolved in concentrated acid solutions and converted to sugar, a precursor for making ethanol. A dilute sulfuric acid hydrolysis process was used to make ethanol during World War I in plants in Georgetown, SC and Fullerton, LA. Wood hydrolysis received considerable attention in Europe during the period between the World Wars I and II. Wood hydrolysis plants were operative in Germany and Switzerland during World War II, and even, today, wood hydrolysis plants are operating in the Soviet Union.

But, methanol and ethanol are not the only transportation fuels that might be made from wood, A number of possibilities exist for producing alternatives. The most promising biomass fuels, and closest to being competitive in current markets without subsidy, are ethanol, methanol, ethyl-tert-butyl ether, anti methyl-tert-butyl ether. Other candidates include isopropyl alcohol, sec-butyl alcohol, tert-butyl alcohol, mixed alcohols, and tert-a mylmethyl ether.

Ethanol or grain alcohol is not restricted to grain as a feedstock. It can be produced from other agricultural crops and lignocellulosics such as wood. It has often been advocated as a motor fuel, and has been used frequently in times of gasoline scarcity. Today Brazil is the only country that uses large quantities of ethanol as a motor fuel, but even in the U.S. we use close to a billion gallons per year. In Brazil, 95 percent alcohol is used as a neat fuel or anhydrous ethanol is used in admixture with gasoline, In the U.S. we use anhydrous ethanol in mixtures of 10 percent ethanol with 90 percent gasoline. The high cost of ethanol production in comparison to gasoline is a major disadvantage, and in the U.S. only large subsidies for biomass ethanol make it competitive. The Federal subsidy is scheduled to expire at the end of 1992. However, because of the perceived ability of ethanol and other oxygenated fuels including alcohols and ethers to reduce air pollution in 90 carbon monoxide and ozone nonattainment areas in the U. S., the cost disadvantage may become secondary, at least in these areas. Other reasons for considering fuels alternative to petroleum include energy security within national borders, balance of trade, and tax policies.

According to the report, *Ethanol Economic and Policy Tradeoffs,* USDA, ERS Agricultural Economic Report Number 562, ethanol production costs vary considerably. However, a suggested estimate of production cost from corn is $1.41 to $1.52 per gallon. Other relevant data for comparison of production costs from grain and wood follow.

U.S. Ethanol Production in 1987:

Production capacity	1260-1335 million gallons (953 million gallons from grain)
Production	1043 million gallons (850 million gallons from grain)
Imports	149 million gallons
Exports	19 million gallons
Used for motor fuel	800-880 million gallons
Production costs	$1.41-$1.52 per gallon (USDA Agric. Econ. Rept. 562)
Yicid from grain	2.5 gallons per bushel
Total corn production	7-8 billion bushels

Ethanol From Wood

Current production---- 11,000 gal/day from spent sulfite liquor sugars

U.S. History----two plants operated 1915-20 on Southern pine sawdust

Yield by process:

Dilute acid hydrolysis	55 gallons per ton
Pretreatment + enzyme hydrolysis	50-80 gallons per ton

Production costs:

One estimate we have is from Raphael Katzen Associates International, Inc. for a pretreatment + enzyme hydrolysis process. They estimate an ethanol selling price of $1.10 to $ 2.30 per gallon based on a 2000 ton per day newsprint feed stock and a 35 million gallon per year capacity. This is a yield of 50 gallons per ton based on a thermo-mechanical pretreatment and pilot plant testing. It also assumes certain municipal bond financing arrangements that would be appropriate for construction and operation of a municipal solid waste facility. The low selling price assumes a $60 per ton of newsprint tipping fee credit and the high selling price is with no cost for newsprint.

Since newsprint is generally 80 percent or more groundwood fibers, the process is suitable for producing ethanol from wood. The economics, however, would be quite different for a wood-to-ethanol plant because of feedstock costs and financing. The wood cost for ethanol production is expected to be about $35 per dry ton and, it is unlikely that similar financing arrangements would be available since it would not be a municipal solid waste plant. With a $35 per ton wood cost, the selling price would be $3 per gallon. However, with wood costs of $36 per ovendry ton and 85 gallons per ton yield, researchers at the Solar Energy Research Institute forecast process improvement possibilities to reduce costs to as low as $0.60 per gallon of ethanol. If this low-cost production can be attained, it will be a significant breakthrough.

The dilute acid hydrolysis process has not been adequately demonstrated to determine all of the process steps and it is expected that the selling price would be higher than $3 per gallon without other product co-production credits.

Besides comparisons in production costs, there is a question whether ethanol at the same price per gallon as gasoline is of equal value. The fuel value of ethanol is less, only 76,500 BTU's per gallon as compared to 124,800 for gasoline. However, ethanol is higher octane than gasoline and for that reason it might attain about the same mileage per gallon as gasoline. We are therefore assuming a gallon of gasoline and a gallon of ethanol to be of equal value.

Another possility for oxygenated fuels is methanol. Methanol could conceivably be made from grain, but its most common source is natural gas. Use of natural gas is better for reducing carbon dioxide production in comparison to other fossil fuels, but use of renewable fuels instead of natural gas would be still better. It can be made from coal or wood with more difficulty and lower efficiency than from natural gas. The cost of making methanol from natural gas is around $0.40 per gallon and it could probably be sold as a motor fuel for about $0.60-S0.70 per gallon, Since gasoline has greater fuel value per gallon (the fuel value of methanol is only 64,500 BTU per gallon), this would be equivalent to gasoline selling at about S0.92 to $1.03 per gallon. In 1985 a consulting firm, Stone and Webster, estimated that under the most favorable conditions, with a wood from methanol plant located away from a deep-water port, methanol from wood could be competitive at a cost of $0.70 to S1.11 per gallon for methanol from other sources. Much of the benefit for a wood to methanol plant would result from savings in shipping cost for methanol from natural gas plants that are currently located near deep-water ports.

President Bush, in a number of statements has proposed a program to develop clean fuels. A report released at the end of September, 1989 by EPA followed through with backing for methanol as a fuel for road vehicles. The study counters earlier claims by the American Petroleum Institute (API) that methanol vehicles would emit uncontrollable emissions of formaldehyde. The EPA report indicates that formaldehyde exposure from methanol-powered vehicles would be less than or equal to that from gasoline-using vehicles. However, API disagrees with the report's findings. The status of formaldehyde, a listed carcinogen, is still unclear. However, EPA cites clear benefits for methanol in other considerations.

According to EPA's findings, the primary environmental benefit of methanol will be significant improvements in ozone levels in the most seriously polluted areas of the country. Substituting methanol for gasoline as a motor fuel, according to EPA, will also lower the air toxic impact of motor vehicle emissions and reduce incidence of cancer. EPA adds that considering the pollutants (benzene, gasoline, refueling vapors, butadiene, and polycyclic) that are emitted from gasoline vehicles and classified as either known or probable carcinogens, projected reductions in the number of cancer cases as a result of clean fuels such as methanol are significant. The report states that volatile organic compound (VOC) emissions from a methanol-fueled vehicle consist mainly of unburned methanol, only about one-fifth as reactive as average gasoline vehicle hydrocarbon emissions. On a reactivity equivalent basis, EPA reckons that methanol flexible fuel vehicles would emit 30 percent less VOC'S than typical future gasoline-powered vehicles, while optimized methanol vehicles would emit 80 percent less.

Methanol has long been used as the fuel for race cars at Indianapolis and some other race tracks, not only because of its clean-burning characteristics, but also because of its efficiency, low tire hazard, and high octane rating.

High octane rating is characteristic of all oxygenated fuels, including ethanol, methanol, ethyl-tert-butyl ether, and methyl-tert-butyl ether. A large part of the success of ethanol from grain in the current U.S. mix of motor fuels is its ability to raise octane rating in a 10 percent mixture of ethanol with 90 percent gasoline. However, it is the recent phenomenal growth in the use of methyl-tert-butyl-ether (MTBE) as an octane enhancer that has captured worldwide attention. MTBE is made by reacting isobutylene with methanol. Ethyl-tert-butyl ether (ETBE) is made by using ethanol instead of methanol, Thus either ethanol or methanol from either grain or wood could be a factor in making tert-butyl ether octane enhancers. The characteristics of ethers are generally closer to those of gasolines than those of alcohols. Ethers are benign in their effect on fuel system materials and are miscible in gasoline; therefore, they are not subject to phase separation in the presence of water, as are methanol and ethanol. Ethers are nonpolar. They are of low volatility and thus give low evaporative emissions.

A few areas have mandated the use of oxygenates during the winter. Colorado took the initial action, instituting it in the Frontal Range area focused on Denver. In the winter of 1987-88, a fuel with at least 1.5 percent oxygen was required. About 90 percent of the fuel in this period used a gasoline blend having 8 percent MTBE, and the other 10 percent was gasohol (10 percent ethanol with 90 percent gasoline). Authorities considered the program to be successful, and in the winter of 1988-89 they required fuel with at least 2 percent oxygen (11 percent MTBE). EPA now permits use of 15 percent MTBE if going to this higher level is desired in the future. EPA has encouraged this approach based on assessment of potential benefits that show between 10 and 20 percent CO reduction over the next decade.

Alternative fuels from wood, as well as grain, have a potential for being competitive with gasoline and diesel motor fuels from petroleum, even without subsidization. Today, ethanol from grain and a slight amount from wood are competing, but only with a large Federal and some State subsidies. For ethanol to compete directly, without subsidy, oil would probably have to sell for $40 or more per barrel. However, environmental and octane-enhancing benefits of ethanol and other oxygenated fuels that may be produced from grain and wood may make them worth more than comparisons on fuel value alone would indicate.

Diesel fuel or gasoline from wood are possibilities through a number of approaches. The one that appears simplest is to use an exudation or gum from a tropical wood species, *Copaifera,* which is said to be directly combustible in a diesel engine. The Fischer-Tropsch pyrolysis process, used successfully for converting coal to synthesis gas in South Africa could also be used to make synthesis gas from wood. Synthesis gas could then be used to make gasoline or diesel fuel. Or mcthanol could be produced from wood and then, by a catalysed reaction known as the Mobil process, be transformed to gasoline.

Although, ideally, there should be additional pilot testing for any process to produce ethanol or methanol from wood commercially, technology for ethanol production has been developed and subjected to some pilot testing. The technology is available for fairly rapid implementation, should the need for alternative fuels become pressing as the result of another global petroleum emergency. Depending on feedstock costs and other variables, ethanol from wood might or might not be able to compete with ethanol from corn. Another important consideration is production and marketing of byproducts such as high fructose corn syrup and distillers dry grains from corn and molasses and/or furfural from wood. The two-stage, dilute sulfuric acid hydrolysis process as developed and pilot tested at the Forest Products Laboratory and the Tennessee Valley Authority National Fertilizer Development Center is a possibility for commercial application in producing ethanol from low-grade hardwoods.

In the two-stage hydrolysis process, for every 100 kg of ovendry wood feedstock about 20 kg carbohydrates suitable for processing to ethanol are obtained from the second stage. There are more carbohydrates derived from the first stage, about 24.9 kg, but many of these first stage carbohydrates are not necessarily fermentable to ethanol.

Ethanol is a possibility if xylose can be fermented to ethanol economically. Fermentation of the xylose and glucose from the first stage could result in almost doubling the ethanol production as compared to only fermenting the glucose from the second stage. Other possible products from the first stage carbohydrates are single-cell protein, furfural, and feed molasses.

Methanol was once produced from wood as a byproduct of charcoal manufacture, but overall yields were low. To produce methanol from wood with a significantly higher yield would require production of synthesis gas in a process similar to that used for production of methanol from coal. Such processes for gasifying wood are less fully developed than the two-stage hydrolysis process for production of ethanol,

Another consideration in producing liquid fuels from wood is the amount of wood availible to manufacture the fuels. For converting wood to liquid fuel, the most optimistic assumption normally used is that wood could be converted to liquid fuel in the ratio of BTU in liquid fuel/BTU in wood = 0.5. At least in the short run it would be difficult to find more than 100 million dry tons of wood per year (1.7 Quads equivalent) for this purpose. This would calculate to be a maximum of 13 billion gallons per year if the output were methanol and the energy content of a ton of dry wood is assumed to be 17 million BTU'S. On the order of 11.5 billion gallons per year would be needed if methanol were added to gasolinc at the rate of 10 percent methanol to 90 percent gasoline.

Project ions of wood use for energy to 2010 are quite modest. We are producing about 2.7 Quads of energy from wood now. Projections of the total for 2010 are about 4.0 Quads. This does not provide for a total growth of even 1.7 Quads. However, if wc really want to get serious about doing something to deter atmospheric CO2 accumulation the availability of wood for energy, including solid as well as liquid fuel, could be increased, I don't believe that 10 Quads per year would be unrealistic. This runs counter to decreased usage of wood for all purposes, particularly from the National forests, to provide more wilderness, habitat for threatened and endangered species, clean water and other environmental considerations. However it must be remembered that, in some cases, more harvesting and clean-up of residues is needed to increase the vigor of forest growth, to protect the forest against wildfire, and to prepare the soil for new growth. In many cases open broadcast burning of logging slash is being outlawed, and harvest of this material for fuel instead of open burning is a viable option for better forest management as well as for profit.

The forests of our country and our growing and increasingly scarce landfill spaces that are 44 percent paper can be an ally in combating the threat of global climate change by providing renewable liquid fuels as well as other benefits, but we have to make sure that we plan intelligently to accomplish this.

Printed on recycled paper