Chapter 5

Ethanol as a Gasoline Blending Agent or Neat Fuel in Highway Vehicles

Although methanol generally is acknowledged as the least expensive of the alcohol fuels, ethanol (ethyl alcohol) has gained support because of its potential contribution to the U.S. agricultural economy. Proponents of ethanol usage either as a blending agent or a neat fuel argue that its expanded use as an automotive fuel will displace imported oil, aid the farm economy by creating a stable new market for its agricultural feedstocks, and improve air quality by reducing emissions from vehicles using it. Ethanol's close tie to the U.S. agricultural system separates it from the other potential alternative fuels.

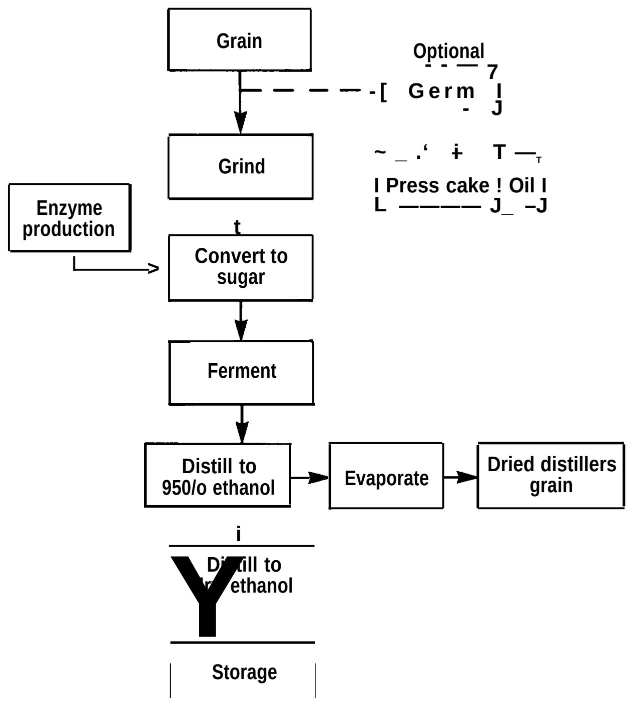
As shown in figure 5-1, in making ethanol, the distiller produces a sugar solution from the feedstock (in the United States, usually corn, sometimes sugar crops), ferments the sugar to ethanol, and then separates the ethanol from the water through distillation. In distillation, the water-ethanol solution is boiled and the vapors pass through a column causing numerous evaporation-condensation cycles, each one of which further concentrates the ethanol.

Currently, nearly a billion gallons of ethanol per year are added to U.S. gasoline stocks to create "gasohol, ' a 90 percent gasoline/10 percent ethanol blend. The U.S. Government and about a third of the States subsidize ethanol use by partly exempting gasohol from gasoline taxes. The subsidy is critical to ethanol economics. For example, the exemption from the Federal tax alone yields a subsidy of $0.60/gallon of ethanol (at the pump, the tax exemption for gasohol is $0.06/gallon, and 1 gallon of ethanol is contained in 10 gallons of gasohol). Each additional penny of State tax exemption for gasohol is worth an additional $0.10/gallon subsidy to ethanol.

EFFECTS ON AIR QUALITY

In looking to ethanol use as an aid to reducing automotive air pollution, the sought-after benefits are quite different for blends and neat ethanol use. The addition of small quantities of ethanol to gasoline-as in gasohol—is viewed primarily as a means to reduce carbon monoxide emissions; use of neat ethanol is viewed primarily as a means to

Figure 5-l—Process Diagram for the Production of Fuel Ethanol From Grain



SOURCE: Office of Technology Assessment, 1980.

reduce concentrations of urban ozone, by reducing the reactivity of the organic component of vehicle emissions.

The use of ethanol blends has been demonstrated to reduce levels of carbon monoxide emissions from existing automobiles. This effect originates from the alcohol's causing engines to effectively run more "lean," that is, the air/fuel mixture will contain more oxygen (because the ethanol itself contains oxygen), and the availability of the oxygen assists in the combustion of CO to CO_2. It had, until recently, generally been thought that the extent of CO reduction would differ according to the vehicle's ability to adjust to changes in air/fuel oxygen content: for older vehicles that do not adjust at all, the effect was known to be large; for the most modern vehicles with systems that automatically compensate for changing air/fuel ratios, the effect was assumed to be small. Recent tests of vehicles with so-called "adaptive learning" have cast doubt on this assumption, however. The Environmental Protection Agency (EPA) now considers vehicles with adaptive learning to be likely to obtain average CO benefits from the use of ethanol and other oxygenated fuels "similar in magnitude to the benefits of closed-loop vehicles in general."[1] The greatest benefits occur during cold start operation, when vehicles produce the major part of total trip CO emissions, but some benefit continues even after warmup.[2] If these conclusions hold up, the use of ethanol and other oxygenates in gasoline blends will continue to be an effective strategy for CO reduction even after the fleet consists primarily of vehicles with modern pollution controls.

The effect of ethanol blends on ozone production has been a controversial issue. Ethanol/gasoline blends have higher volatility than the original gasoline, yielding an increase in net evaporative emissions of VOCs. Without counterbalancing changes, this increase would lead to aggravation of urban ozone problems. In fact, there has been substantial debate about requiring gasoline volatility to be adjusted downwards to compensate for the volatility increase caused by addition of the ethanol. Previous studies have concluded that use of ethanol blends *without a restriction on resulting fuel volatility* would likely yield an overall increase in ozone concentrations.[3]

It now appears that volatility adjustment is *not* necessary to prevent an increase in ozone formation from ethanol blend use. Carbon monoxide also plays a role in ozone formation, and the reduced carbon monoxide emissions associated with ethanol blend use will tend to reduce ozone formation. In addition, the incremental evaporative emissions will be somewhat less reactive than evaporative emissions from straight gasoline. Although the net effect of these changes will vary with gasoline composition, atmospheric conditions, and vehicle emission control equipment, recent government studies indicate that future use of ethanol blends, assuming modern vehicles, low volatility gasoline, and no volatility corrections made for blending, will have negligible impact on urban ozone levels.[4]

The net effect of using ethanol blends on the full range of emissions is not as clear. For one thing, the leaning effect, aside from reducing CO, will increase engine-out emissions of NO_x.

The use of neat ethanol in light-duty vehicles should have air quality effects similar to but milder than those associated with methanol use; ethanol is somewhat between methanol and gasoline in its physical characteristics, for example, ethanol's stoichiometric air/fuel ratio is about 9:1 compared to methanol's 6.4: 1 and gasoline's 14.5:1. In general, reactive hydrocarbon emissions should go down substantially, but the effect on ozone may be countered somewhat by higher emission levels of acetaldehydes, and development of more effective aldehyde controls will be a crucial factor in ethanol's overall air quality benefits. Assuming use of three-way catalysts with stoichiometric air/fuel ratios, emissions of carbon monoxide should be at levels similar to those of gasoline engines, and NO_x emissions may also be about the same.

COST COMPETITIVENESS

Few ethanol proponents have tried to argue that the consumer costs of ethanol, without government subsidies, could be competitive with gasoline. Recent work by the Department of Agriculture has shown that, assuming the range of corn and byproduct prices that has occurred during the past decade, the full cost of ethanol production from a new plant[5] ranges from $0.85 to $1.50/gallon,[6] compared to wholesale gasoline prices of about $0.55/gallon, with gasoline energy content nearly 50 percent greater than an equal volume of ethanol.

[1] C.A. Harvey, Technical Support Staff, Emission Control Technology Division, U.S. Environmental Protection Agency, draft memorandum to C.L. Gray, Director, Emission Control Technology Division, USEPA, September 1989.

[2] Ibid.

[3] National Advisory Panel on the Cost-Effectiveness of Fuel Ethanol Production *Fuel Ethanol Cost-1.?'activeness Study,* November 1987; also, M.R. Segal et *al., Analysis of Possible Effects of HR. 2052, Legislation Mandating Use ofEthanol in Gasoline,* Congressional Research Service report 87-819 SPR, Oct. 13, 1987.

[4] R. Scheffe, *Five City UAM Study Summary Report,* U.S. Environmental Protection Agency (Research Triangle Park, NC, in press).

[5] For moderate increases in ethanol production capacity, ethanol plants could be added to existing wet mills at a substantial saving in capital cost. However, any realistic large-scale use of ethanol, especially as a neat fuel, would require construction of new plants on a stand-alone basis.

[6] S.M. Kane and J.M. Refry, *Economics ofEthano/Production in the United States,* Agricultural Economic Report No. 607, United States Department of Agriculture, March 1989.

In directly comparing ethanol production costs to gasoline costs, the price of the corn feedstock is the most volatile component. The net cost of the corn in ethanol (full cost minus byproduct sales) ranged from 10 cents to over 70 cents per gallon of ethanol produced from 1980 to the present.[7] Other costs will vary depending on the technology selected, scale, and whether or not the plant is added to an existing corn milling operation or built as a new stand-alone plant.

Although there are several wet milling plants of sufficient scale to allow new, cost-competitive ethanol plants to be added, any large-scale expansion of ethanol production will require building new stand-alone plants. The Department of Agriculture study estimates that capital charges for a new plant would be $0.38 to $0.48/gallon of ethanol produced,[8] that is, the total production cost of each gallon of ethanol includes $0.38 to $0.48 allocated to plant capital payback.

Given these pessimistic comparisons of the *direct* costs of ethanol and gasoline, the economic argument for ethanol has centered around the positive economic impact its widespread use would have on the American farm economy, and the large savings that would accrue to the U.S. treasury because of reductions in farm support payments. These benefits are claimed to justify extension of the current Federal subsidy ($0.60/gallon) granted to ethanol use in gasohol, and the possible expansion of this subsidy to neat ethanol use in vehicles.

The true long-term costs to the U.S. economy of ethanol production and use are difficult to calculate. One reason is that different interest groups disagree about how to calculate these costs, or even whether to classify certain items as costs at all; another is that several of the cost components depend on the state of agricultural markets, which can change radically over time. For example, large-scale ethanol production is widely expected to increase the price of corn, the most likely ethanol feedstock, and possibly other crops and grain-fed livestock[9] as well. Agricultural interest groups consider this a positive benefit of ethanol production, since it will raise farm income; consumer interest groups consider higher food costs a net cost of ethanol production. Furthermore, the net change in food prices will depend on overall demand for agricultural products. If the agricultural economy is generally depressed, the price elasticity of corn supply will be high and the net cost to consumers of ethanol production will be low; if agriculture is booming, the opposite will be true.

OTA has twice examined the net costs of large-scale ethanol production and use, most recently in 1986.[10] The studies concluded the following:

1. *The size of the byproduct market. The* costs of ethanol production are highly dependent on the markets for the byproduct of ethanol distillation, corn stillage. The stillage is a high protein substitute for soybean meal as livestock feed; when the stillage can be sold as a protein substitute, net feedstock costs go down substantially. If markets for the stillage as a protein supplement became saturated, the stillage would have much lower value and might even represent a cost (for disposal). Under these circumstances, the net costs of ethanol production from corn would change markedly for the worse. Thus, the actual size of the byproduct market and the potential for increasing it are important issues to the ethanol debate. OTA concluded that the byproduct market could saturate when ethanol production reached a few billion gallons per year. At production levels beyond this point, net ethanol production costs would become substantially higher than even the high ($0.85 to $1.50/gallon) costs noted above. However, development of overseas markets for the byproduct could substantially increase the level of production that could be attained without saturating the market; the state of international trade and foreign requirements for high protein feeds add an important uncertainty to ethanol cost calculations.

[7] Ibid.

[8] Ibid.

[9] It is possible, however, that livestock prices may go down, if the increased availability of distiller's grains drives down the price of this feed.

[10] Office of Technology Assessment, "Staff Memorandum on the Effects of Replacing Lead With Aromatic Versus Alcohol Octane Enhancers in Gasoline," Jan. 6, 1986; and earlier, Office of Technology Assessment, *Energy From Biological Processes* (Washington D.C.: National Technical Information Service, July 1980). The more recent study examined the use of ethanol in blends only, whereas the earlier study examined the full range of potential ethanol uses.

2. *Effects of different ''states of the farm economy."* For the type of farm economy of the late 1970s, e.g., expanding demand, high land rents, etc., and with conservative (low) estimates of the magnitude of the byproduct market, OTA calculated that with ethanol production rates as low as 2 to 4 billion gallons per year, further production could yield a negative balance of oil and gas (that is, we would use more energy from oil and gas to produce the ethanol than the oil energy we would save when the ethanol replaced gasoline) and a cost to consumers, in terms of higher food prices, of $4 to $5 per additional gallon of ethanol produced.[11] On the other hand, for markets more typical of recent conditions, with a larger byproduct market and lower agricultural demand, an ethanol production rate of 4 billion gallons per year could yield a cost to consumers (in higher food prices) of about $0.45 to $0.75 per additional gallon produced and a net gain in oil and gas.

Ethanol is promoted as a means of raising farm income. However, this is also the goal of current farm programs. Although the costs of both ethanol subsidies and conventional farm support programs will fluctuate considerably from year to year, OTA's earlier analysis concluded that the cost of government subsidies needed to sustain a large-scale ethanol industry would most likely be higher than the cost per year of achieving the same (farm income) results with applicable parts of current farm programs. Other studies have concluded the opposite. For example, the General Accounting Office's (GAO) econometric study for the House Energy and Commerce Committee concluded that likely net revenues to the Treasury from a moderate scale ethanol program would be positive.[12] However, the GAO study did *not* attempt to calculate potential increases in ethanol prices, and states that ''efforts to stimulate a *large-scale (our* emphasis) expansion could raise ethanol feedstock production costs to a point that ethanol could not compete with other fuels.''[13]

The Congressional Research Source, (CRS) in a parallel analysis of ethanol blends,[14] also arrived at conclusions more optimistic than OTA's. This result occurs in part because CRS believed that byproduct markets would not saturate, or that such saturation could be prevented. The analysis implies that a government subsidy to replace half of all gasoline with gasohol would raise consumer food prices by $6.6 billion/year, decrease farm subsidies by $3 to $7 billion/year, and require additional ethanol subsidies of about $1 to $3 billion/year.[15] These results imply a ''net cost" to the consumer[16] of $0.6 to ***$6.6*** billion/year, or a subsidy of about $0.12 **to $1.30** for each gallon of gasoline replaced with ethanol. Other economic effects include an increase in farm income of about $1 billion/year, a decrease in oil imports of $1.1 to $2.4 billion/year (at 1987 oil prices), and a decrease in grain exports of about $500 million.[17]

In any event, OTA is skeptical of the ability of available econometric models—including the ones used by GAO and CRS—to properly account for the extensive crop switching that would likely occur in a large expansion of corn acreage for methanol production (e.g., a likely switch from sorghum to corn in Nebraska, and increased sorghum acreage in Texas), for changes in farm energy consumption with overall expansion of planted acreage, and other complex factors.

[11] Office of Technology Assessment, Energy ***From Biological Processes,*** op. cit., footnote ***4;*** and Office of Technology Assessment, Staff Memorandum, 1986, op. cit., footnote 4. About 40 percent of the increased prices—$1.60 to $2.00/gallon of ethanol-would go to farmers, based on historical relationships.

[12] J. England-Joseph, U.S. General Accounting Office, "Perspectives on Potential Agricultural and Budgetary Impacts from an Increased Use of Ethanol Fuels," testimony before the Committee on Ways and Means, U.S. House of Representatives, Feb. 1, 1990.

[13] Ibid.

[14] Although the CRS report examined the effects of a government *requirement* fo, ethanol use, the analysis can be applied to a direct subsidy of ethanol production.

[15] OTA estimated the required subsidy using the CRS calculation of additional production costs associated with producing gasohol, and assuming that the Federal subsidy would equalize gasoline and gasohol production costs.

[16] Adding changes in consumer prices to changes in Federal expenditures, assuming that consumers will eventually absorb the expenditure changes in their tax payments.

[17] Segal et al., op. cit., footnote 3.

In most cases, corn is the least expensive agricultural feedstock for ethanol production, especially when the byproduct of the production process can be sold. Wood and plant wastes are less expensive inputs to the ethanol plant, but the costs of available ethanol conversion processes for these materials are higher, so that the net total cost of ethanol made from wood and plant wastes is more expensive than ethanol made from corn. Future improvements in these conversion technologies could alter these conclusions, however; the Solar Energy Research Institute (SERI) currently is actively working towards improving wood-to-ethanol processes, and they believe that achievement of economic competitiveness at $20/barrel oil-or ethanol costs below $1.00/gallon-may be obtained by the year 2000 (The Tennessee Valley Authority, New York State Energy Research and Development Authority, and others are also pursuing this technology). A wood-to-ethanol process achieving this cost goal would need to be capable of converting a very high percentage of the feedstock to ethanol and other energy products (primarily methyl aryl ethers, or MAE, high-octane compounds that can be used as blending agents with gasoline) at low temperature and pressure--most likely involving enzymatic hydrolysis processes combining simultaneous hydrolysis and fermentation, xylose fermentation (30 to 60 percent of the sugars in wood are xylose), and lignin conversion.[18] Important barriers remain to pulling output as high as necessary and reducing costs sharply, including problems such as ethanol inhibition of the hydrolysis enzymes, prevention of enzyme degradation and denaturation at higher temperatures, sterility and contamination risks of enzyme recycling, and so forth, as well as the overall problem of optimizing the many process steps. Although we agree with SERI that this work is worth pursuing-especially because of the greenhouse benefits to be gained by commercial success—we find it difficult to share their strong optimism about the timing and eventual outcome of the work.

Another potential means of reducing ethanol costs is to substitute alternative separation technologies—e.g., membrane filtration--for distillation in the production process. Use of these technologies would also reduce energy use in the production process and reduce ethanol's net fuel cycle emissions of greenhouse gases. OTA has not evaluated these technologies, but they are not now commercially available for this use.

Table 5-l—Environmental Impacts of Agriculture

Water
- Water use (irrigated only) that can conflict with other uses or cause ground water mining.
- Leaching of salts and nutrients into surface and ground waters, (and runoff into surface waters) which can cause pollution of drinking water supplies for animals and humans, excessive algae growth in streams and ponds, damage to aquatic habitats, and odors.
- Flow of sediments into surface waters, causing increased turbidity, obstruction of streams, filling of reservoirs, destruction of aquatic habitat, increase of flood potential.
- Flow of pesticides into surface and ground waters, potential buildup in food chain causing both aquatic and terrestrial effects such as thinning of egg shells of birds.
- Thermal pollution of streams caused by land clearing on stream banks, loss of shade, and thus greater solar heating.

Air
- Dust from decreased cover on land, operation of heavy farm machinery.
- Pesticides from aerial spraying or as a component of dust.
- Changed pollen count, human health effects.
- Exhaust emissions from farm machinery.

Land
- Erosion and loss of topsoil decreased cover, plowing, increased water flow because of lower retention; degrading of productivity.
- Displacement of alternative land uses-wilderness, wildlife, esthetics, etc.
- Change in water retention capabilities of land, increased flooding potential.
- Buildup of pesticide residues in soil, potential damage to soil microbial populations.
- Increase in soil salinity (especially from irrigated agriculture), degrading of soil productivity.
- Depletion of nutrients and organic matter from soil.

Other
- Promotion of plant diseases by monoculture cropping practices.
- Occupational health and safety problems associated with operation of heavy machinery, close contact with pesticide residues, and involvement in spraying operations.

SOURCE: Office of Technology Assessment, 1980.

ENERGY AND ENVIRONMENTAL EFFECTS

Ethanol production's energy balance and environmental effects depend primarily on the expansion of corn production and the markets for ethanol production byproducts. Increased corn production will take place on land that is more environmentally sensitive and energy intensive than average cornland--or it will displace other crops onto such land. Table 5-1 lists the environmental impacts of agriculture, many of which could be particularly important if ethanol

[18] J.D. Wright, "Ethanol From Biomass by Enzymatic Hydrolysis," *Chemical Engineering Progress,* August 1988, pp. 62-74.

production is large enough to add significant amounts of marginal land into intensive crop production.

The expansion of crop production onto new lands will occur slowly as long as there is a market for the corn stillage byproduct of ethanol distillation. Since the stillage is a substitute for soybean meal, when the stillage can be sold as a protein substitute, the energy use and other negative environmental effects (erosion, pesticide and fertilizer use, etc.) of extra corn production for ethanol are somewhat balanced by the reduction in soybean cropping. For example, an average of about 0.8 acres of soybeans are replaced by the stillage associated with 1 acre of corn, so the net effects on land use maybe only 20 percent of the increased corn acreage. Similarly, the net increase in farming energy use (corn use minus soybean savings) is about 30 to 40 percent of the energy content of the resultant ethanol, compared to an increased farming energy use of 160 percent or more of the energy content of the resultant ethanol (leading to a net energy loss) if there is no displacement of soybean production.

The costs and energy savings of ethanol use are also dependent on the energy savings associated with ethanol's ability to boost the octane level of gasoline. Some refineries are able to use these properties of ethanol to reduce their energy needs slightly. Today's refiners have made the necessary investments to produce current high octane gasolines in a manner that is well integrated into their overall operation.[19] Because addition of ethanol generally was not factored into their investments, the opportunities for obtaining energy savings by adding ethanol are limited today. As a result, the marginal energy savings from each additional percent of ethanol addition drops rapidly after the first percent or two. However, this conclusion may not hold if refiners are forced to respond to requirements to change gasoline makeup to reduce emissions, adding new capital equipment and changing operating practices. Given the uncertainty associated with the probable makeup of so-called "reformulated gasolines" (see ch. 8), ethanol's possible role, and energy savings associated with that role, are difficult to predict but worthy of reexamination as knowledge about appropriate gasoline changes finally emerge from ongoing research programs.

Ethanol use has also been promoted as a means of reducing the $C0_2$ emissions associated with gasoline usage. Achieving a net reduction in CO_2 will be difficult, however, because the sum of the increase in farming energy (as noted above, 30 to 40 percent of the energy in ethanol *in the best case)* and distillery energy (assuming current technology) would require about the same amount of fossil fuels as found in the ethanol itself. Fuel cycle fossil fuel use could be reduced if renewable were used to power the distillery, substantial energy savings were achieved by commercializing membrane filtration or other alternative separation technologies to replace distillation, or larger-than-expected efficiency gains were achieved in ethanol use. On the other hand, saturation of byproduct markets would increase ethanol fuel cycle net energy use, with a net *increase in CO_2* emissions, because the energy savings associated with the byproduct's substitution for soybeans will be lost.

The CO_2 issue has become quite controversial because of the strong claims of ethanol proponents and recent analyses which support the position that ethanol use produces less net CO_2 than gasoline. Marland and Turhollow,[20] for example, calculate net $C0_2$ emissions from the ethanol fuel cycle at about 37 percent of gasoline emissions-implying a major greenhouse benefit. However, Marland and 'Ihrhol-10W'S assessment uses a series of assumptions which raise serious concerns for a large ethanol production program:

1. *The feedstock corn is grown on an average acre producing 119 bushels.* Yield projections for additional corn crops are a critical source of uncertainty for both energy use and economic projections. For one thing, the land used will not be 'average' land, it will be inferior to the average. For a large ethanol program, corn production will either move to marginal acreage or displace other production onto marginal acreage. The net result is that the farming energy that should be assigned to ethanol production is considerably larger than the ''average' energy used here. The frost two additional billion gallons of ethanol can be produced using set-aside land—land which, although cropped in past years, generally

[19] OTA Staff Memorandum, op. cit., footnote 10.

[20] G. Marland and A. Turhollow, ''CO_2 Emissions from production and Combustion of Fuel Ethanol from Corn,'' Migdon Segal, *Ethanol Fuel and Global Warming,* Congressional Research Service report 89-164 SPR, Mar. 6, 1989.

represents each farmers' least-productive, most energy-intensive land. If production moves to more marginal lands, energy use and environmental damages will increase further.

Tending to counteract these adverse land quality effects, future crops may produce greater yields through better plant breeding or genetic engineering; also, high fertilizer and pesticide prices and a growing awareness of environmental problems caused by overuse of agricultural chemicals may well lead to lower overall use and, probably more *efficient* use of these chemicals in the future. Finally, farmers may try to substitute varieties of corn with greater starch yields, to maximize ethanol yield per acre. Higher starch yields would likely trade off with lower protein byproduct yields, so the use of this strategy would depend on the state of the byproduct market.

While it is unlikely that average *incremental* yields from a greatly expanded corn crop would be as high as the national 10 year average used in this analysis, we recognize that the estimate can be, at best, an educated guess, and there are factors pushing these yields in both directions from the average.

As a final note, Marland and Turhollow's use of the 119 bushels/acre yield has been criticized as representing only "successful" acreage and ignoring planted acreage that was not harvested.[21] The 119 bushels/acre estimate appears to be essentially correct, however. Although there is a substantial difference between reported plant acreage and harvested acreage, the difference is primarily accounted for by land planted for corn sileage (that is, for the carbohydrate value of the plant material rather than the protein value of the grain). This land is counted in the estimate for planted corn acreage but left out of the estimate for harvested corn acreage.

2. *The "byproduct credit" to be subtracted from the total energy use and $C0_2$ production is proportional to the market value of the ethanol and byproduct.* This results in subtracting nearly 50 percent from the total CO_2 production, which is much too high. The energy required to produce enough soybeans to replace the distillery byproducts is about 8,000 Btu/gallon of ethanol, or one-fifth the amount subtracted.
3. *All of the distillery byproducts will be consumed in their highest use.* With the production of billions of gallons of ethanol, there is a real possibility of saturating the byproduct market. If this occurs, the byproduct credit cannot be taken.

Ethanol distribution and use should be safer than gasoline distribution and use. In a spill, ethanol in high initial concentrations will be quite toxic to marine life, but ethanol is highly soluble and will disperse rapidly, it is readily biodegradable, and it will evaporate quickly if spilled on land.[22] Also, cent contamination of drinking water supplies is less troublesome than for gasoline or methanol because ethanol is less toxic to humans in equal concentrations and has a recognizable taste (methanol does not, although fuel methanol would likely contain a taste additive for safety) .23 Ethanol has fire safety implications similar to those of methanol: compared to gasoline, it has lower volatility, higher flammability limit, lower vapor density, lower heat of combustion, and higher heat of vaporization, which means an ethanol spill is less likely than gasoline to ignite and, if it ignites, will burn more slowly and less violently than a gasoline fire.[24] And along with methanol, special protection must be taken to prevent fuel ignition inside storage tanks, and additives will be necessary to impart flame visibility.[25]

The greenhouse balance of ethanol use would likely be improved substantially, and the environmental impacts reduced, if processes for producing ethanol from wood and wood waste were perfected and costs substantially reduced. The overall greenhouse and environmental balance would depend importantly on the energy balance of the wood

21 S.P. Ho, Amoco Oil Co., "Global Warmin g Impact of Ethanol versus Gasoline," 1989 National Conference on Clean Air Issues and America's Motor Fuel Business, Oct. 3-5, 1989, Washington D.C.

22 U.S. Environmental protection Agency, *Analysis of the Economic and Environmental E fleets of Ethanol as a Motor Fuel,* special report (draft), Nov. *15, 1989.*

23 Ibid.

24 Ibid.

25 Ibid.

production system (minimum use of agricultural chemicals, harvesting integrated into wood production for other uses), the sustainability of the system (intensive harvesting of wood wastes can deplete soils of critical minerals), and the avoidance of forest management problems that have plagued U.S. forestry in the past. Table 5-2 lists key impacts of logging and forestry that must be avoided or mitigated if wood-to-ethanol (or methanol) systems are to be environmentally sound. Systems based on producing wood as a crop, e.g., coppicing fast-growing species that will regenerate from stumps, resemble agriculture more than forestry and will need to deal with agricultural impacts.

DEMAND LIMITS

Ethanol production is theoretically limited by the rate at which grain, sugar, and cellulosic feedstocks can be supplied on a continuing basis, or up to several tens of billions of gallons per year. In principle, there is no limit to ethanol demand up to total oil demand, as long as ethanol is used as a direct substitute for gasoline or other oil products. However, market demand for ethanol *as a blending agent will* likely be quite small without government intervention.[26] Ethanol must compete with methanol, methyl tertiary butyl ether (MTBE), and other products for the oxygenate blend market. It must compete with refinery isomerization, polymerization, alkylation, and reforming as a means of boosting gasoline octane. In addition, the total oxygenate content of gasoline in the United States currently is limited by EPA regulations and by the fuel capabilities of current automobiles. In the longer term, ethanol also must compete with various other synthetic fuels and with advanced procedures for increasing octane.

ETHANOL OUTLOOK AND TIMING

Ethanol is, in several ways, an attractive automobile fuel. It is likely to provide important emissions benefits over gasoline, though the benefits of neat ethanol, or ethanol blended with small amounts of gasoline, must be considered uncertain because of a lack of experience with vehicles equipped with U.S.-type emission controls. It is basically a safer fuel than gasoline to distribute and use, it has a convenient liquid form, and its volumetric energy content is higher than the other leading alternative fuel contenders, minimizing range problems.

The major roadblock to its introduction and use as a major transportation fuel is fuel supply. Ethanol is most cheaply produced from corn, and the energy, environmental, and economic effects of a substantial increase in ethanol use in the automotive fleet will be highly dependent on the state of the agricultural economy at the time and on the con.figuration of the production system created to provide the ethanol.

Table 5-2—Potential Environmental Effects of Logging and Forestry

Water
- Increased flow of sediments into surfaoe waters from logging erosion(especially from roads and skid trails.
- Clogging of streams from logging residue.
- Leaching of nutrients into surface and ground waters.
- Potential improvement of water quality and more even flow from forestation of depleted or mined lands.
- Herbicide/pesticide pollution from runoff and aerial application (from a small percentage of forested acreage).
- Warming of streams from loss of shading when vegetation adjacent to streams is removed.

Air
- Fugitive dust, primarily from roads and skid trails.
- Emissions from harvesting and transport equipment.
- Effects on atmospheric CO_2 concentrations, especially if forested land is permanently converted to cropland or other (lower biomass) use or vice-versa.
- Air pollution from prescribed burning.

Land
- Compaction of soils from roads and heavy equipment (leading to following two impacts).
- Surface erosion of forest soils from roads, skid trails, other disturbances.
- Loss of some long-term water storage capacity of forest, increased flooding potential (or increased water availability downstream) until revegetations occurs.
- Changes in fire hazard, especially from debris.
- Possible loss of forest to alternative use or to regenerative failure.
- Possible reduction in soil quality/nutrient and organic level from short rotations and/or residue removal (inadequately understood).
- Positive effects of reforestation-reduced erosion, increase in water retention, rehabilitation of strip-mined land, drastically improved esthetic quality, etc.
- Slumps and landslides from loss of root support or improper road design.
- Temporary degrading of esthetic quality.

Ecological
- Changes in wildlife from transient effect of cutting and changes in forest type.
- Temporary degradation of aquatic ecosystems.
- Change in forest type or improved forest from stand conversion.

SOURCE: Office of Technology Assessment, 1980.

[26] At the time this report was being prepared, Clean Air Act proposals concerning the required oxygen content of gasolines being considered by the Congress would, if approved, have the effect of stimulating ethanol use.

Some studies have suggested that the U.S. treasury, at least, would benefit from increased ethanol production with the current $0.60/gallon subsidy because of more-than-balancing reductions in farm subsidies. OTA considers these results to be highly uncertain, and we believe it is more likely that the subsidy would outweigh the reduced farm supports in the long run-especially if production were to grow quite large. Also, because the demand for agricultural products can shift directions quite rapidly (particularly because of the volatility of export markets) whereas an ethanol infrastructure cannot, a subsidy of ethanol production may prove to be a cumbersome tool for agricultural policy. And a strategy to increase ethanol use must recognize the possibility that an ethanol production system, unless specifically designed to minimize the use of oil plus natural gas, may save little of these fuels when all portions of the production system are accounted for. Finally, policymakers must be aware that much of the potential benefit to the farm economy from ethanol production will arise from higher food prices, and consumers will count this benefit as a cost.

These policy concerns, coupled with ethanol's high direct costs, imply that prospects are not favorable for substantial increases in ethanol use in transportation *relying on the current ethanol production system.* Short-term improvements in the current system-commercializing membrane separation for distillation, for example, assuming costs can be reduced--could enhance ethanol's costs and energy balance somewhat, but seem unlikely to provide the boost necessary for a major production increase. For the long-term-beyond the year 2000--ethanol may have better prospects given the potential for relatively inexpensive production from wood and wastes. The enzymatic hydrolysis processes needed are being actively pursued by the Solar Energy Research Institute and others, and important advances have been achieved, but the outcome of current research must be considered uncertain.