# I. TECHNICAL ASPECTS OF GASOHOL

ETHANOL PRODUCTION

## Commercial Distillation

The production of gasohol requires the integration of a number of factors, two of which are considered in this section -- ethanol distillation facilities and their feedstocks. Although ethanol can be produced from any feedstock capable of being reduced to the proper sugars, present U.S. production technologies rely on sugar and starch feedstocks. Suitable ethanol crops include corn, wheat, grain sorghum, sugarcane, sugarbeets, sweet sorghum, and Jerusalem artichokes. There is, however, no “best” ethanol crop, since different crops will be superior for ethanol production in different soil types and regions of the country. Current research into sugar and starch feedstock alternatives to corn are likely to produce strains that will outperform corn under some circumstances.

In addition to primary crop production, there are numerous sources of spoiled grain and food processing wastes that can be used to produce ethanol, but their total potential is small (1,2). Other processes are under development that will permit the commercial distillation of ethanol from cellulosic (cellulose containing) feedstocks such as crop residues, grasses, wood, and the paper contained in municipal solid waste.

The ethanol conversion process consists of four basic steps. First, the feedstock is treated to produce a sugar solution. The sugar is then converted in a separate step to ethanol and carbon dioxide by yeast or bacteria in a process called fermentation. The ethanol is removed by a distillation process which yields a solution of ethanol and water that cannot exceed 95.6% ethanol (at normal pressures) due to the physical properties of the ethanol-water mixture. In the final step the water is removed to produce dry ethanol. This is accomplished by adding to the solution a chemical that changes these physical properties and by distilling once again.

The material remaining in the water solution after the ethanol is distilled away, called stillage," contains some dead yeast or bacteria and the material in the feedstock which was not starch or sugar. Grain feedstocks, for example, produce a high protein stillage (called distillers' grain) which can be used as an animal feed* while sugar and cellulose feedstocks produce a stillage with little protein and less feed value.

At the present time 15-20 million gallons of fuel ethanol per year are being produced commercially in the U.S., and domestic capacity sho~d increase to 40-90 million gallons per year by the end of 1980.(3) New distilleries (e.g. , 50 million gallons per year) can be brought on stream in only two years, and idle capacity can often be converted in one year or less. Beyond 1980 the information is sketchy, but there is at least 50-70 million gallons per year of new capacity which 1s under study or has been ordered and which can be in production in 1981.(3) In addition to domestic production, American Gasohol (Mineola, N.Y.) is planning to import 120 million gallons of ethanol per year from Brazil.(4)

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* The exact nutritional value of distillers' grain in its various forms is still uncertain (e.g., the amounts that can be used in animal feed and the effect of using wet stillage as a feed). This is a subject that is currently being researched.

Looking towards the future, there are several processes uncle r development which will be able to use cellulosic feeds tocks as sources of sugar for ethanol production. til of the processes require higher capital investments (2-3 times higher than conventional processes)(5) because of expensive pretreatments, and this limits their present applicability. There are, however, a number of approaches to cellulose conversion which can improve its competitiveness by lowering the production costs of ethanol. These include lower capital charges through favorable financing, substantial credits for byproduct chemicals, improved ethanol yields (gallons per ton of feedstock), and process innovations. A process developed by Gulf Oil Chemicals Co., for example, uses municipal waste paper, and municipal bond financing would make the distillery competitive with conventional processes. (Because of the higher capital investment, special financing lowers the ethanol cost more than for grain distilleries.) Another cellulose process, developed in the U.S. during World War II and used commercially in the USSR, produces ethanol from wood. The process has recently been reevaluated(6) as a source of ethanol and byproduct chemical feedstocks (e.g., phenol and furfural). Although the capital investment for the distillery is three times that of a corn distillery, the byproduct credits are of sufficient value to make the ethanol competitive. The chemical industry, however, is unlikely to make the commitment to these feedstocks that would be necessary to support a large ethanol program until more information is available on the relative merits of biomass and coal derived chemical feedstocks. (7)

Aside from special financing or large byproduct credits, the key to making cellulosic feedstocks competitive is to achieve high ethanol yields without the use of expensive equipment, excessive loss of process chemicals, or the production of toxic wastes. At present there are no processes which fulfill all of these criteria. Current research and development efforts, however, could lead to significant results in 3-5 years, and commercial facilities could be available by the late 1980's.

Another way to reduce the costs of ethanol from cellulose is through process innovation. There are several possibilities for improvements, including minor changes which take advantage of the low purity requirements for fuel ethanol, and major process innovations for concentrating and drying the ethanol. An additional possibility involves a fundamentally different process for ethanol production. Rapidly heating cellulosic materials produces a gas which contains ethylene, a chemical that can be converted to ethanol with commercially available technology. Although this process is still at the laboratory stage, preliminary calculations indicate that the costs and yields could compare favorably to fermentation, and the process would require less energy. (8) It is unlikely, however, that the entire process could be made commercially available before the 1990's.

On-Farm Distillation

Apart from commercial distilleries, there has been interest expressed in the role which individual farmers can play in ethanol production. Producing ethanol on the farm, however, faces a number of limitations which may severely restrict its widespread practice.

On site distillation of ethanol for farm use may be possible at a cost of $1.00/gallon of 95% ethanol plus labor. * If it is used as a fuel supplement for retrofitted diesel driven tractors this would be equivalent to diesel fuel costing $1.70 per gallon. (9) Current diesel prices would therefore have to double for ethanol production to be competitive without subsidies.

cost estimates significantly below this are apparently based on ignoring equipment and/or fuel costs, assigning a credit for the byproduct animal feed that is significantly higher than its market value, and/or producing ethanol containing significantly more water than the 5% assumed above.

If the purpose of on-farm distillation is to develop a degree of energy self-sufficiency, the higher cost of ethanol may be acceptable. Due to technical limitations, however, ethanol can displace only 35% of the diesel fuel used in retrofitted diesel engines. (9)

Limitations also apply where distillation is viewed as a process for diverting significant quantities of grain produced on the farm. A typical farm of 500 acres could produce 50,000 bu. of corn, of which 1,000 bu., or 2%, would provide as much ethanol (2,500 gallons) as could reasonably be

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* While equipment costs will vary considerably depending upon how automatic they are, $1 for each gallon per year of capacity is plausible. Assuming this equipment cost, the costs per gallon of ethanol are: $0.58 for net feedstock cost, $0.20 for equipment costs (operated at 75% of capacity), $0.20 for fuel (assuming $3/MMBTu and 67,000 BTU/gallon) and $0.05 for enzymes and chemicals, resulting in $1.03/gallon of ethanol or $0.98/gallon of 95% ethanol.

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used as a diesel fuel substitute in retrofitted diesel engines. (9, 10) Converting 20% of the crop to ethanol would produce 25,000 gallons, far more than could be used on the farm, and would require a significant investment of probably $25,000 or more.

The quality of the ethanol most easily produced on farms across the nation is likely to limit the uses for which it would be appropriate. As a gasoline additive, for example, ethanol must be free of water in order to avoid operating problems. (9, 11) Not only would producing dry ethanol change the economics of on-farm distillation, but the current drying processes involve the use of dangerous chemicals. Alternate processes using drying agents, or desiccants, can probably be developed, but the costs are uncertain. (12)

On-farm production of dry ethanol could become competitive with commercially distilled ethanol if relatively automatic mass-produced distilleries could be sold for less than $1 for each gallon per year of capacity and if farmers charge little for their labor. Although 150,000 gallon per year package distilleries producing 95% ethanol can be bought for prices approaching this value (13), OTA is not aware of any farm size (1,000 - 10,000 gallon per year) package distilleries for producing either 95% or dry ethanol. The price goal for automatic, on-farm, dry ethanol production is not unrealistic, but it will probably require process innovations, particularly in the drying step, and could well involve the use of small, inexpensive computers for monitoring the process.

Other concerns about on-farm distilleries involve the fuel used to operate them and the possible diversion of the alcohol produced. As with large distilleries, abundant or renewable domestic energy sources should be used to fuel the on-farm distilleries, the most appropriate of which may be crop residues (using gasifiers currently under development). Another possibility is the use of solar powered distilleries, but the costs are uncertain.* Obtaining appropriate energy sources for distilleries need not be a problem, but it is something that should be considered in legislation designed to encourage on-farm distillation.

The ethanol produced with most processes can easily be converted to beverage alcohol.** Although ethanol can be denatured to render it unfit for consumption, regulations will be difficult to administer.

For some farmers the cost and/or labor required to produce ethanol may be of secondary importance. The value of some degree of energy self-sufficiency and the ability to divert limited amounts of corn and other grains when the market price is low may outweigh the inconvenience and/or costs. The Bureau of Alcohol, Tobacco and Firearms has received over 2,800 applications for on-farm distillation permits and they expect 5,000 by the end of the year. (14) As a profitable venture, however, on-farm production of ethanol is, at best, marginal.

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* The key problem is that concentrating a 10% ethanol solution to 95% ethanol requires a theoretical minimum of 25 evaporation-condensation cycles. Since a solar powered water distillery only produces one evaporation-condensation cycle, the ethanol solution would have to be put through a still of this type many times in order to concentrate the ethanol. Designs better suited to ethanol concentration, however, can probably be developed.

** Dilute to 50% with water and filter through activated charcoal.

# GASOHOL AS AN AUTOMOBILE FUEL

Between 150-200 million gallons of gasohol per year are being sold in over 800 service stations in at least 28 states, and the major U.S. automobile manufacturers have extended their warrantee to permit the use of gasohol. (2, 15) Despite its increasing acceptability and use, however, there are several technical aspects which merit consideration. These include fuel stability, drivability, octane boosting properties of ethanol, and mileage with gasohol. These points are considered below.

## Fuel Stability

Only minute quantities of water will dissolve in gasoline and although the addition of ethanol increases the water volubility somewhat, gasohol containing more than 0.3% water can separate into two phases, or layers, which can cause automobiles to stall. Although some additives designed to prevent phase separation with 95% ethanol have been tested, none has proven to be fully satisfactory. (9) Consequently, gasohol blends require dry (anhydrous) ethanol, and storage and transport tanks must be kept free of moisture. Although there have been occurrences of phase separation in a few service stations, if dry ethanol is used and due care taken, this should not be a significant problem.

## Automobile Performance

For most automobiles, performance with gasohol should be indistinguishable from that with a gasoline of the same octane. A small but unknown fraction of the existing automobile fleet, however, will experience surging, hesitation, and/or stalling with gasohol, due to a variety of causes.* (9) But these problems should disappear with time as gasohol use

* The leaning effect of gasohol, damage to gaskets, pump diaphragms, etc., and dislodging of deposits in the fuel system leading to clogging in the fuel filter and/or carburetor.

becomes more widespread and the automobile fleet is replaced with new cars manufactured to accept gasohol.

Octane

An important advantage of gasohol is that its octane* is higher than the gasoline to which the ethanol has been added. The exact increase will depend on the octane and composition of the gasoline and can vary from an increase of 0.8 to 5 or more octane numbers. (16) For "average" gasolines the increase is about 3-4 octane numbers.

Raising the octane of motor fuels would enable automobile manufacturers to increase the efficiency of automobile engines, but this is unlikely to occur unless gasohol is widely available. Alternatively, the octane of the gasoline blended to gasohol can be lowered to exactly compensate for the octane boosting properties of the ethanol. If this is done, there is an energy savings at the refinery of 88,000-150,000 BTU per barrel of oil refined. (9, 16, 17) If these energy savings are attributed solely to the ethanol, a savings of 0.27-0.45 gallons of gasoline equivalent can be achieved for each gallon of ethanol used.** Achieving this savings, however, will require the cooperation of oil refiners and distributors.

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* Average of motor and research octane.

** The median energy savings is 118,000 BTU per barrel of crude oil refined (higher heat content). Since an average of 55% of a barrel of crude oil is turned into gasoline, and this gasoline is mixed with one ninth as much ethanol, then the 118,000 BTU savi-ngs is attributed to about 2,6 gallons of ethanol. With a higher heat content of 125,000 BTU/gallon for gasoline> this results in 0.36 gallons of gasoline per gallon of ethanol.

In order to realize the energy savings of ethanol it is essential that car owners use a fuel with the correct octane. If drivers buy a higher octane gasohol than their cars require, based perhaps on advertising claims of its superiority, the energy savings would be negated.

Mileage

Ethanol contains less energy per gallon than gasoline, and a gallon of gasohol contains 3.8%* less energy than a gallon of gasoline. If all other factors were equal, this would result in 3.8% lower mileage (miles per gallon ). The gasohol, however, also "leans" the fuel mixture (i. e., moves the air-fuel mixture to an effective value that contains less fuel and more air) which increases the thermal efficiency (miles per BTU) in many cars, but lowers it in a few.

The mileage measured for gasohol varies considerably from test to test, but road tests have often registered better mileage averages than laboratory tests. The results of the road tests, however, are less accurate than

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* The lower heat content of ethanol and gasoline are about 76,000 BTU/gallon and 117,000 BTU/gallon, respectively. In addition 0.9 gallon of gasoline plus 0.1 gallon of ethanol results in 1.002 gallons of gasohol. Blending the alcohol result in a 3.6% drop and the expansion an additional 0.2%0 This number, however, can vary somewhat for different gasoline compositions.

laboratory tests* and have sometimes been conducted on vehicles which are not representative of the U.S automobile fleet. Based on laboratory data, the mileage (miles per gallon) for gasohol is expected to average O-4% less than for gasoline.

## ENERGY BALANCE

The energy objective of an ethanol fuel program is the displacement of foreign oil and gas with a domestic synthetic fuel. The impact of such a program depends upon the energy balance of growing the feedstock, converting it to ethanol, and using the ethanol as fuel. The fuels used in the conversion process must also be considered.

For each gallon of ethanol derived from corn, farming and grain drying consume, on the average, the energy equivalent of 0.29 gallons of gasoline

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* The data available from the 2 million mile gasohol test, (18) for example, have been analyzed by OTA. Using a standard statistical test ("t" test) reveals that the spread in data points (standard deviation) is so large that the mileage difference between gasohol and regular unleaded would have to be more than 30% (2 times the standard deviation) before OTA would consider that the test had demonstrated a difference in mileage. While more sophisticated statistical tests might indicate that the measured difference in mileage is meaningful, the validity of these statistical methods is predicated on all the errors being strictly random; and the assumption of random errors is suspect unless the number of vehicles in the test fleet is orders of magnitude larger than any tests conducted to date.

in the form of oil (for fuel and petrochemicals) and natural gas (for nitrogen fertilizers). (10) The exact amount, however, will vary with farming practices (e.g., irrigation) and yields. Although corn is often cited as an energy intensive crop (due to the high energy inputs per acre cultivated), the energy used per ton of corn grain produced is comparable to results achieved with other grains. (lo) In general, however, the energy input per gallon of ethanol produced will increase when the farmland is of poorer quality (e.g., set-aside acreage) and/or in dryer or colder climates (i.e., most of the western half of the country, excluding Hawaii).

The fuel used in the distillation process is perhaps the most important factor in determining the displacement potential of ethanol. Even under the most favorable circumstances, distillery energy consumption is significant. Although the distillery producing most of the fuel ethanol used today reportedly consumes 0.25 gallon of gasoline equivalent (0.24 in the form of natural gas) per gallon of ethanol, (14) the derivation of this number involves some arbitrary decisions about what energy inputs should be attributed to the facility’s food processing operations, and various factors probably would make the process unsuitable* for extensive use in fuel ethanol production. Energy

1) The distillery probably uses waste heat from an adjacent byproduct processing plant which consumes nearly as much energy as the distillery but is not included in the energy balance cited here, 2) acetaldehyde is left in the ethanol which increases evaporative emissions and the possibility of vapor lock in automobiles, and 3) the economics are predicated on credits for byproducts (e.g., corn oil), whose markets could be saturated.

efficient stand alone fuel ethanol distilleries would consume the equivalent of 0.4-0.6 gallon of gasoline per gallon of ethanol. (5, 20) To maximize the displacement potential of ethanol it is therefore essential that distilleries use abundant or renewable domestic energy sources such as coal, biomass, and/or solar heat. As shown in the following table, reliance on these fuels would reduce the total use of oil and gas at the distillery to insignificant levels.

The amount of petroleum displaced by ethanol fuel also depends on the manner in which it is used. AS an additive in gasohol, each gallon of ethanol displaces about 0.8 gallons of gasoline. If the oil refinery produces a lower grade of gasoline to take advantage of the octane boosting properties of ethanol, an additional 0.36 gallon of gasoline equivalent can be saved in refinery processing energy, as described on page 11.

Additional energy savings are achieved by using the byproduct distillers' grain as an animal feed. To the extent that crop production is displaced by this animal feed substitute, the farming energy required to grow the feed crop is displaced.

In all, the total displacement of imported fuels achieved per gallon of ethanol can be increased by a factor of 2.5 by requiring that 1) petrolem and natural gas not be used to fuel ethanol distilleries and 2) lower octane gasoline be used in gasohol blends.

Table 1 summarizes the oil and natural gas used and displaced for the entire gasohol fuel cycle. The quantities are expressed as gallons of gasoline equivalent for each gallon of ethanol produced and used

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Table 1 Energy Balance of Gasohol from Corn

Oil and Natural Gas Used (+) and Displaced (-)

(in gallons of gasoline equivalent per

gallon of ethanol produced and used[a])

| | | Set Aside and Potential Cropland | |
|---|---|---|---|
| | Present | Coal Fired Distillery | Coal Fired Distillery & Lowering of Gasoline Octane |
| Farming | 0.29 | o.35b) | o.35[b]) |
| Distillery | 0.24 | @ | @ |
| Distillery Byproduct | -o.09[d]) | -OJ19° | -o.09[d]) |
| Automobile | -0.80 | -0.80 | -0.80 |
| Oil Refinery | | | -0.36 |
| Total | -0.j6(~0.3) | -o.54(fo.3) | -o.90(q).3) |

a Lower heat content of gasoline and ethanol taken to be 117,000 BTU/gallon and 76,000 BTU/gallon, respectively.

b Estimated uncertainty of ~o.ls.

c 50~_0UL1-?f1,00o BTU of coal per gallon of ethanol.

d Assumed that distillers' grain replaces corn grown on average cropland.

Source: OTA

in gasohol. The three cases presented correspond to (1) the present situation, (2) future production of ethanol from the less productive land that can be brought into crop production and using coal as a distillery fuel, and (3) the same as (2) except that the octane of the gasoline is lowered to exactly compensate for ethanol's octane boosting properties. These cases result in net displacements of (1) slightly more than 1/3 gallon, (2) slightly more than 1/2 gallon and (3) slightly less than 1 gallon of gasoline and natural gas equivalent per gallon of ethanol used.

It should be noted, however, that if oil or natural gas is used as a distillery boiler fuel, the second case could result in the fuel cycle consuming slightly more oil and natural gas than is displaced. This is the situation that is alluded to in most debates over gasohol's energy balance, but it is a situation that can be avoided with appropriate legislation.

In the most favorable case (case (3) above) and with an energy efficient distillery, however, the ratio of total energy displaced to total energy consumed is 1.5 (±0.4), i.e., the energy balance is positive (a ratio greater than 1). And if the feedstocks are derived from more productive farmland, or local conditions allow energy savings at the distillery (e.g., not having to dry the distillers' grain), then the balance is even more favorable. Alternatively, an energy credit could be taken for the crop residues, which would also improve the calculated balances This general approach to the energy balance, however, does not consider the different values of liquid versus solid fuels.

The uncertainty factor in Table 1 of plus or minus 0.3 gallons of gasoline per gallon of ethanol is due primarily to inherent errors in fuel efficiency measurements, differences in farming practices and yields, and the magnifying effect on these errors of the low (10%) ethanol content of gasohol. These factors make it.unlikely that more precise estimates can be made in the near-term.