Chapter 10

USE OF ALCOHOL FUELS

Chapter 10.–USE OF ALCOHOL FUELS

TABLES

FIGURE

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Introduction

Liquid fuels have some unique advantages over sol ids and gases that make them important fuels in some applications. They contain a large amount of energy per unit volume (as compared to gases) and their combustion can easily be controlled (as compared to solids). However, there are substantial differences among liquid fuels. At one end of the spectrum is residual fuel oil, which can produce considerable emissions when burned and is generally best suited as a boiler fuel (an application also open to solid fuels). At the other end are light distillate oils, gasolines, and alcohol fuels. The oils and gasolines are superior to alcohols with respect to their energy content per unit weight (ethanol has two-thirds and methanol one-half of the energy per gallon of gasoline), which makes them better suited for aviation. The alcohols are superior to oils with respect to their lower particulate emissions and higher octane values. These properties make them particularly useful for marine and ground transportation where energy density is not critical and for gas turbines used for peak load electric generation, the applications considered here.

While both ethanol and methanol are alcohols, they have different physical and chemical properties. Of the two, methanol is less soluble in gasoline, separates easier, and can more easily damage certain plastics, rubbers, and metals used in current automobiles. Furthermore, methanol requires more heat to vaporize it. Both alcohols, as contrasted to gasoline, contain oxygen and conduct electricity. These properties are important when considering the use of alcohol fuels.

While oil and hydrocarbon (HC) crops may some day produce fuels for transportation, their costs and yields are highly uncertain at this time. For the near to mid-term, the most likely biomass substitutes for gasoline, diesel, and light fuel oil are the alcohol fuels.

Biomass is the only solar technology for producing liquid fuels. The biomass can be converted to methanol ("wood alcohol") through thermochemical conversion or to ethanol ("grain alcohol") through fermentation or, possibly, thermochemical conversion. Ethanol production from sugars and starches is currently commercial technology. Wood-to-methanol plants can be built with existing technology, although none currently exists, and plant-herbage-to-methanol technology needs to be demonstrated.

Most cost calculations indicate that methanol from coal will be less expensive than either alcohol from biomass. Until and unless a domestic liquid fuels surplus develops, however, this cost difference is not likely to exclude the biomass alcohols from the market.

Spark Ignition Engines—Effects From Alcohols and Blends

Alcohols make excellent fuels for spark-ignited engines which are designed for their use. However, when considering alcohol or alcohol-gasoline blend use in gasoline engines, there are four specific factors that are of over**riding importance. One factor is the material from which the engine is constructed. Another is the ratio of air to fuel** (A/F **ratio) in the mixture that is burned in the engine. A third is** proper fuel distribution among the cylinders, and a fourth is cold-starting ability.

Some materials in some automobiles are incompatible with alcohols. Contact with alcohols can damage some gaskets, fuel pump diaphragms, and other plastic and rubber parts. If these parts are adversely affected or fail, the engine is likely to malfunction. Furthermore,

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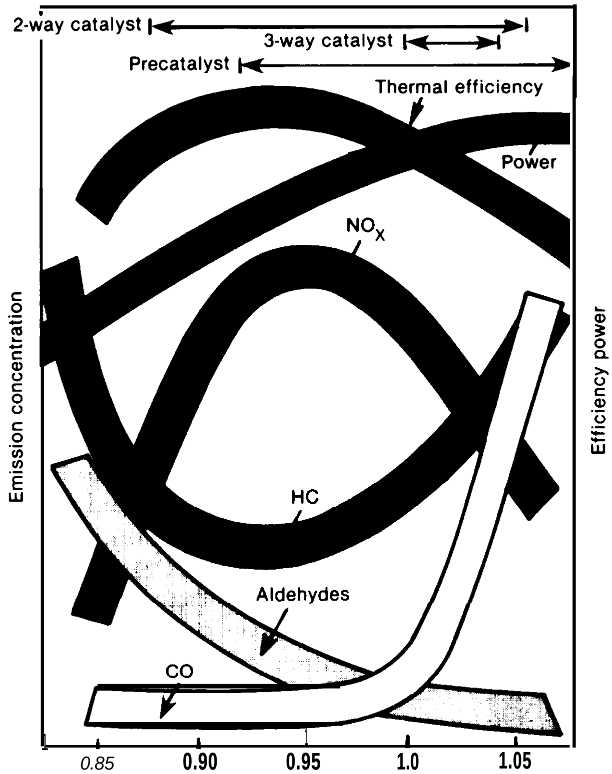
some electric fuel pumps are mounted in the fuel tank. Electric currents induced in the alcohol fuels by these motors may cause the protective terneplate coating on fuel tanks to dissolve and leave the tank susceptible to corrosion. There may also be a fire hazard associated with electrical shorting. Under certain circumstances, not totally understood at present, the alcohols or blends can also chemically **remove the terneplate coating.**[123] **Finally, alcohols can cause some deposits** in the fuel tanks and lines to loosen and dislodge, leading to a blockage **in the fuel filter or carburetor.**

Three major classes of automobiles are in use today: pre-1 975 cars, oxidation (two-way) catalyst cars (most post-1 975 cars in States other than California), and California three-way catalyst cars. The range of A/F ratios* intended for each class of cars is shown in figure 37 together with the effect of this ratio on the engine power, efficiency, and emissions. If the A/F **ratio extends beyond the ranges of this fig**ure, most engines will hesitate or stall. (Stratified-charge engines like the Honda CVCC and Ford Proco have somewhat wider ranges.)

Since the pre-1975 cars and oxidation catalyst cars usually have carburetors with fixed fuel metering passageways, the alcohol blend fuels, which require less air per volume of fuel than gasoline, will make the effective fuel mixture leaner (i. e., move the effective A/F ratio to less fuel and more air). California three-way catalyst cars, however, have a sensor that adjusts the fuel delivery system to the A/F value intended by the manufacturer. Nevertheless, exhausts from alcohol fuels "fool" this sensor somewhat, so the compensation is not com-

Figure 37.—Efficiency, Power, and Emissions as a Function of Equivalence Ratio



The equivalence ratio is the ratio of the A/F ratio which is exactly sufficient to completely burn all of the fuel to the actual A/F ratio used in the car. Leaner mixtures have an excess of air, while richer ones have an excess of fuel.

SOURCE: H Adelman, et al., "End Use of Fluids From Biomass as Energy Resources in Both Transportation and Nontransportation Sectors, " University of Santa Clara, Santa Clara, Cal If., contractor report to OTA, 1979

plete.[4] **Consequently, while the difference between the A/F ratio for alcohol fuels and pure gasoline** is less for California three-way catalyst cars than for other cars, the A/F ratio is still somewhat leaner with alcohol fuels compared to gasoline.

For pure alcohols the fuel metering rate must be increased significantly relative to gas-01 inc. This increased rate can result in streaming flow rather than well-disbursed droplets as the fuel enters the air stream when carburetors are retrofitted for alcohol fuel. This change

'K R Stamper, "50,000 Mile Methanol/Gasoline Blend Fleet Study– A Progress Report, " in *Proceeding of the Alcohol Fuels Technology Third International Symposium,* Asilomar, Calif (Bartlesville, Okla Bartlesville Energy Technology Center, Department of Energy, May 1979)

²S. Gratch, Director of Chemical Science Lab, Ford Motor Co , Dearborn, Mich , private communication, 1979

³J L Keller, G M Nakagucki, and J C Ware, "Methanol Fuel Modification for Highway Vehicle Use, " Union 011 Co of California, Brea, Calif , final report to the Department of Energy, contract No FY 76-04-3683, July 1978

● The figure shows the equivalence ratio which is found by dividing the stoichiometric A/F rat to which is exactly sufficient to completely burn all of the fuel by the actual A/F ratio used in the car Leaner mixtures are to the left and richer to the right

⁴Gratch, private communication, op cit

can seriously aggravate the variation in the A/F ratio among the cylinders which in turn can reduce performance and economy and increase emissions. Proper design of the fuel delivery system and intake manifold can avoid this penalty.

The alcohols do not inherently provide good cold engine starting. Below 400 F, special attention must be paid to avoid cold-starting problems with alcohol. Aids such as electric heating in the intake manifold, blending agents such as gasoline, butane, or pentane added to the alcohols, or auxiliary cold-start fuel are providing solutions to this problem in the alcohol vehicle fleets now in operation.

Gasohol

Materials Compatibility

Gasohol is a mixture of 10 percent ethanol and 90 percent unleaded gasoline. The ethanol blended in gasohol must be dry (anhydrous) or the blend will separate into two phases or layers under certain conditions. Typically, gasohol can hold more water than gasoline, but it can contain no more than about 0.3 percent if separation is to be avoided down to –400 F. Various additives have been tried to improve the water tolerance of gasohol, but none have proved satisfactory to dates

Although the use of anhydrous ethanol should minimize water tolerance problems with gasohol, phase separation has been observed to occur in four service stations in Iowa. ' This phase-separated blend was sold to some customers and caused their vehicles to stall. Both the vehicle tanks and the service station tanks were drained and up to 0.3 percent by volume water was found in the mixture, but the origin of the water contamination is not known.

Gasohol does not appear to significantly affect engine wear as compared to gasoline but more experience with gasohol is needed before a definitive statement can be made. However, an unknown fraction of existing automobiles have specific components that are not compatible with gasohol, which can result in some fuel system failures.

As older cars are replaced with newer ones warranted for gasohol use and as experience develops in handling ethanol-gasoline blends, these problems should gradually disappear.

Thermal Efficiency

The leaning effect of gasohol relative to gasoline will affect the three classes of cars somewhat differently. For precatalyst and oxidation catalyst cars, the thermal efficiency can either increase or decrease with gasohol depending on the original A/F setting (see figure 37). In general, automobiles that operate rich will increase in efficiency, while those that operate lean will decrease in thermal efficiency with gasohol.

The Nebraska "two million mile" test showed a large average mileage increase (7 percent) with gasohol. ' However, the spread of data points is so large that the uncertainty in this difference is greater than the difference itself. * This is a generic problem in trying to deduce small differences in mileage with road tests.

Laboratory tests, however, indicate an increase in thermal efficiency of 1 to 2 percent

5 H Adelman, et al , "End Use of Flu Ids From Biomass as Energy Resources in Both Transportation and Non-Transportation Sectors, " University of Santa Clara, Santa Clara, Calif , contractor report to OTA, 1979,

'Douglas Snyder, Iowa Development Commission, private communication, 1979

'W A Scheller, *Nebraska 2* **Million** *Mile Gasohol* **Road Test Program,** *Sixth Progress Report* (Lincoln, Nebr University of Nebraska, January 1977)

*Taking data from figure 4 of Scheller, OTA has analyzed the uncertainty in the average mileage difference 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 percent (two 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 with gasohol in precatalyst and oxidation catalyst cars, which is within the measurement errors.[8] The changes in thermal efficiency with three-way catalyst cars will be less and therefore negligible.

Since gasohol contains 3.5 percent less energy per gallon than gasoline, precatalyst and oxidation catalyst cars are expected to experience about a zero- to 4-percent decrease in miles per gallon. Three-way catalyst cars are expected to experience about a 3- to 4-percent decrease in mileage. Probably neither of these decreases would be noticeable by motorists and, as stated above, will depend on the A/F setting of the automobile for all but the three-way catalyst cars.

These conclusions are in complete agreement with the results of an American Petroleum Institute study released in the spring of 1980,[9] in which all available data on gasohol mileage were compared, averaged, and treated statistically to determine the significance of the results.

Drivability

Post-1970 noncatalyst and oxidation catalyst cars that are set at lean A/F ratios on gasoline can experience drivability problems such as stumbling, surging, hesitation, and stalling with gasohol due to further mixture leaning. While no drivability problems have been reported for precatalyst cars, laboratory tests on 1978 and 1979 oxidation catatlyst cars suggested slight deterioration in drivability.[10] If the percentage of ethanol is increased beyond 10 percent, more and more cars are expected to experience drivability problems due to the leaning effect.

Since three-way catalyst cars largely compensate for the leaning effect of gasohol, no drivability problems are expected with gasohol, as long as the mixture does not go beyond the capability of the compensation mechanism in these cars.

In most cars there may also be some minor problems with vapor lock, if the vapor pressure of the blend is not adjusted properly by removing some butanes from the gasoline.

Octane

Addition of ethanol to gasoline increases the octane* for the mixture over that of the gasoline. The exact increase will depend on the gasoline, of which there is a great variety. On the average, for the range of 5 to 30 percent ethanol, each percent of ethanol added to one base unleaded regular gasoline (88 octane) raised the octane number by 0.3. However, the octane increases per unit alcohol are larger for lower percentages of ethanol and lower octane gasolines and level off at higher alcohol percentages and gasoline octane. A 10-percent blend would raise the octane by about 2 to 4 using an "average gasoline."[11]

The octane-boosting properties of ethanol can be exploited in either of two ways to save energy: 1) by reducing the oil refinery energy by producing a lower octane gasoline or 2) by increasing the octane of all motor fuels so that automobile manufacturers can increase the compression ratios and thus the efficiency of new cars.

There is considerable uncertainty and variability in the amount of premium fuel that can be saved at refineries by using ethanol as an octane-boosting additive. As shown in table 63, reported or derived values vary from nearly zero to more than 60,000 Btu/gal of ethanol, depending on the average octane of the refinery gasoline pool, the octane boost assumed from ethanol, the type of gasoline and the ratio of gasoline to middle distillates produced by the refinery, the refinery technology used, and other specifics.

[8] R K Pefley, et al., "Characterization and Research Investigation of Methanol and Methyl Fuels," University of Santa Clara, Santa Clara, Calif, contractor report to the Department of Energy, contract No FY 76-5-02-1258, 1979

[9] Mueller Associates, Inc, "A Comparative Assessment of Current Gasohol Fuel Economy Data," commissioned by the American Petroleum Institute, 1980

[10] R Lawrence, "Gasohol Test Program," Technology Assessment and Evaluation Branch, Environmental Protection Agency, Ann Arbor, Mich, December 1978

*Octane here refers to the average of research octane and motor octane.

[11] Keller, Nakagucki, and Ware, op cit

Table 63.–Various Estimates of Refinery Energy Savings From Use of Ethanol as Octane-Boosting Additive

Source	10^3 Btu saved/gal of ethanol blended 10% in gasoline	Conditions
Energy Research Advisory Board[a]	8	Unknown
Kozinski[b]	16	86 pool octane, reduction in gasoline to distillate ratio, 3 octane number boost by ethanol
OTA[c]	40-45	91 pool octane, reduction in gasoline to distillate ratio, 3 octane number boost by ethanol
Adelman[d]	53	Pool of 91 and 96 research octane, 5 research octane boost by ethanol
Office of Alcohol Fuels[e]	63	Unknown

a Energy Research Advisory Board. "Gasohol. " Department of Energy, Apr 29, 1980
b A A Kozinski, Amoco 011 Co, Naperville, Hl private communication, 1980 from data in O K Lawrence, et al , "Automotwe Fuels–Refinery Energy and Economics, ' Amoco 011 Co , SAE technical paper series No 800225, 1980
c OTA from data in Lawrence, Op cit, and from figure 5 In G W Michalski and G H Unzelman, "Effeclwe Use of Antiknocks During the 1980' s.' American Petroleum Institute preprint No 22-79, from 44th Refinery Midyear Meeting, May 16, 1979
d H Adelman, et al , "End Use of Fluids From Biomass as Energy Resources m Both Transportation and Nontransportation Sectors, ' University of Santa Clara, Santa Clara, Cahf contractor report to OTA, 1979
e Office Of Alcohol Fuels, Department of Energy, "Comments by the DOE Off Ice of Alcohol Fuels on the Energy Research Advisory Board, April 29, 1980, Gasohol Study Group, Report," June 3, 1980

SOURCE Off Ice of Technology Assessment

Based on published computer simulations of an oil refinery,[12] Kozinski has estimated a savings of about 16,000 Btu/gal of ethanol on the basis of an average gasoline pool octane of 86, and appropriate reduction **in the gasoline-to-distillate ratio, which is appropriate for the current situation where the octane of about half the gasoline is raised with tetraethyl lead. " In the future, if most of the gasoline produced is unleaded, then the pool** will have to increase to at least 89 octane, which is the current average after lead has been added. Moreover, the octane requirements of new cars is increasing, which will induce refiners to increase the pool octane further.

Assuming an average pool octane requirement of 91, which can be reduced to 88 by the addition of 10 percent ethanol, and assuming an 8-percent reduction in the gasoline-to-distillate ratio from the ethanol, the refinery energy savings from using ethanol as an octane-boosting additive are about 40,000 to 45,000 Btu/gal of ethanol.[15 16] This corresponds to about 0.3 to 0.4 gal of gasoline equivalent per gallon of ethanol.

The refinery energy savings are nonlinear with the pool octane and the greatest savings occur with the first increment of ethanol used. Consequently, since the supply of ethanol will likely be limited to less than a universal 10-percent blend, 0.4 gal of gasoline equivalent per gallon of ethanol is used in the calculations.

If the energy savings from ethanol represent the major economic incentive to the refiner, then refineries with the highest potential for energy savings would be the most likely to use it and savings would be maximized. Some refineries, however, may have additional incentives for using ethanol, including capital savings and greater gasoline yields from reduced reforming requirements, and access to stronger markets with gasohol. These incentives may not coincide with maximum energy savings. Moreover, the widespread use of technically advanced refining methods could reduce the potential for energy savings through ethanol use. Clearly, there are numerous factors which can lower the actual savings below that which is technically possible for the refineries modeled previously.[17 18] Consequently, although 0.4 gal of gasoline equivalent per gallon of ethanol is used as the refinery energy savings, it should be viewed as a potential savings, which probably will not be achieved in practice for all cases. However, too many assumptions about future refinery operations are required in calculating the energy savings to be able to determine a single, correct value; and the actual savings achieved will be very site specific.

[12] D K Lawrence, et al , "Automotive Fuels– Refinery Energy and Economic s," Amoco 011 Co , SAE technical Series No 800225, 1980

[13] A A Kozinski, Amoco 011 Co , Naperville, Ill , private communication, 1980

[14] Bob Tippee, "U S Refiners Adjusting to Changing Requiremerits, " *Oil and Gas Journal*, June 23, 1980

[15] Based on Lawrence, et al , op cit

[16] Based on figure 5 of G W Michalski and G H Unzelman, "Effective Use of Antiknocks During the 1980' s," American Petroleum Institute preprint No 22-79, from 44th Refinery Midyear Meeting, May 16,1979

[17] Lawrence, et al , op cit

[18] Michalski and Unzelman, op cit

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The other possibility is to use the ethanol nationwide to gradually increase the octane of motor fuels. Auto manufacturers could use the increased octane to improve engine efficiencies by increasing the compression ratios in automobile engines. The energy savings per gallon of ethanol would be comparable to that calculated above, but there would be little savings before higher octane fuels were readily available and older automobiles had been replaced with the newer, more efficient engines.

Some stratified-charge engines (e.g., Ford Proco) do not require high-octane fuels and the benefits from a high-octane fuel would be substantially less than for conventional engines. If these or other such engines are used extensively, the octane-boosting properties of ethanol would be of little value, but it is likely that large numbers of automobiles will need high-octane fuels well into the 1990's.

Value of Ethanol in Gasohol

The value of ethanol or the price at which it becomes competitive as a fuel additive can be calculated in several ways. Two alternatives are presented here.

At the oil refinery, each gallon of ethanol used as an octane booster saves the refinery the equivalent of 0.4 gal of gasoline by allowing the production of a lower octane gasoline (see section on octane above). in addition, 1 gal of ethanol will displace about 0.8 gal of gasoline when used as a gasohol blend (i.e., gasohol mileage is assumed to be 2 percent less than gasoline mileage). 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 (gasoline price) + (refinery fuel saved) x fuel price = 0.8 X 1.6 + 0.4 X 1.0 = 1.7 times the crude oil price. *

If the gasoline retailer blends the gasohol, the value of the ethanol is somewhat different. Gasoline retailers bought regular unleaded gasoline for about $0.70/gal in July 1979 and sold gasohol for a rough average of $().()3/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 $0.07 worth of gasoline and the mixture sold for $0.03/gal more. Therefore, 0.1 gal of ethanol was valued at $0.10 or $1 .00/gal. This is 2.5 times the July 1979 average crude oil price of $0.40/gal.

Both of these estimates are approximate, and changing price relations between crude oil and gasoline could affect them. Moreover, several other factors can change the estimated value of ethanol. If a special, low-octane, low vapor pressure gasoline is sold for blending with ethanol, at low sales volumes the wholesaler might assign a larger overhead charge per gallon sold. Also, the refinery removes relatively inexpensive gasoline components in order to lower the vapor pressure* of the gasoline, and this increases its cost. On the other hand, in areas where gasohol is popular, the large sales volumes lower service station overhead per gallon thus raising ethanol's value. These factors can change the value of ethanol by as much as $0.40/gal in either direction (i. e., $0.04/gal of gasohol) and the pricing policies of oil refiners and distributors will, to a large extent, determine whether ethanol is economically attractive as an octane-boosting additive.

Ethanol

If pure ethanol is used, carburetors have to be modified to accommodate this fuel. New engines designed for ethanol could have

*This is in agreement with the value of 16 to 1 8 times the crude oil price that can be calculated using Bonner and Moore's" estimates based on $12 25/bbl crude 011

"*A Formula for Estimating Refinery Cost Changes Associated With Motor Fuel Reformation* (Houston, Tex Bonner and Moore Associates, Inc., Jan 13, 1978)

*The more' volatile components of gasoline (e.g., butanes) may be removed to decrease evaporative emissions and reduce the possibility of vapor lock Although these components can be used as fuel, removing them decreases the quantity of gasoline and the octane boost achieved by the ethanol Consequently, the advantages of having a less volatile gasoline must be weighed against the resultant decrease in the gasoline quantity and the value of the ethanol This is a matter of business economics in each refinery and there are no simple rules which would be universally applicable higher compression ratios (due to the higher octane of ethanol) and burn leaner fuel mixtures which would improve engine efficiency; and laboratory tests indicate the improvement could be 10 to 20 percent.[20 21] Furthermore, the increased compression ratio provides more power, so engine sizes could also be reduced, thereby increasing the efficiency still further.

In cold climates there can be problems starting and during warmup of engines fueled by pure ethanol, due to its low volatility and high heat of vaporization. Consequently, special equipment will be necessary to enable cold starting in vehicles fueled with straight ethanol. Alternatively, it may be possible to blend small quantities of light hydrocarbons in the alcohol to alleviate the cold-start problem, or one could use a combination of these strategies.

Methanol= Gasoline Blends

In general the effects of adding methanol to gasoline are similar to those for ethanol addition, but more extreme. Thus methanol separates from gasoline at lower moisture levels and damages alcohol-susceptible parts and some paints[22] more quickly or extensively. Therefore, there would be some added cost associated with using metals, plastic and rubber parts, or paints that are tolerant to methanol over using those tolerant to ethanol, but the added cost is probably quite small.

As with ethanol, the change in thermal efficiency for methanol-gasoline blends depends on the original gasoline A/F ratio, but would generally be in the range of zero to 4 percent for a 10 percent methanol blend, leading to an estimated 1- to 5-percent drop in mileage (miles per gallon).

The octane boost that can be achieved with methanol is comparable to that for ethanol, or about 3 octane numbers for a 10-percent blend.[23 24]

For cars adjusted lean on gasoline, drivability problems will occur with a 10 percent methanol blend due to additional leaning. However, at lower percentages of methanol, these problems decrease. Indeed methanol is used as a de-icer at concentrations of about 0.5 percent, with no apparent impairment of drivability.[25]

The principal problems with methanol blends are the large increase in vapor pressure when methanol is added and the poor water tolerance of the blends. The higher vapor pressure can lead to increased evaporative emissions and possibly vapor lock. The decreased water tolerance can lead to fuel separation (into layers), which can lead to poorer drivability in automobiles.

The vapor pressure of the blend can be decreased by reducing the gasoline vapor pressure, but this significantly reduces the volume of gasoline blending stock and can result in less total automotive fuel.[26] Newer cars, however, are fitted with charcoal to trap evaporative emissions from fuel tanks,[27] but these filters may have to be replaced yearly in order to maintain their effectiveness.[28] Evaporative emissions from carburetor boiloff increase with alcohol blends. However, charcoal air filters are being used on some 1980 model vehicles to trap the evaporative emissions from the carburetor and may reduce blend evaporative emissions. Moreover, fuel injection systems have less fuel losses. Vapor lock may also be a problem in some cases,[29] but studies indicate

[20] H Menrad, "Recent Progress in Automotive Alcohol Fuel Application," in *Proceedings of the Fourth International Symposium on Automotive Propulsion Systems*, held on Apr 18-22, 1977, (NATO Committee on the Challenges of Modern Society, February 1978)

[21] Winfried Berhardt, "Possibilities for Cost-Effective Use of Alcohol Fuels in Otto Engine-Powered Vehicles," in *Proceedings of the International Symposium on Alcohol Fuel Technology, Methanol and Ethanol*, West Germany, Nov 21-23, 1973, english translation by the Department of Energy

[22] Keller, Nakagucki, and Ware, op cit

[23] Adelman, et al, op cit

[24] F W Cos, "The Physical Properties of Gasoline/Alcohol Automotive Fuels," in *Proceedings of the Third International Symposium on Alcohol Fuel Technology, vol. II*, Asilomar, Calif May 28-31, 1979

[25] Adelman, et al, op cit

[26] Keller, Nakagucki, and Ware, op cit

[27] Ibid

[28] K R Stamper, Bartlesville Energy Technology Center, Department of Energy, Bartlesville, Okla, 1979

[29] Keller, Nakagucki, and Ware, op cit

that proper vehicle design can also eliminate this problem .30

The water tolerance problem may require some sort of cosolvent, or additive, which helps to retain methanol in gasoline. * One such cosolvent, t-butanol (another alcohol), is currently being test marketed in t-butanol-methanol-gasoline blends by Sun Oil.[32] The energy cost of producing the t-butanol, however, is not known. Alternatively, hexanol (still another alcohol) has been used successfully to recombine the phases in a separated methanol-gasoline blend .33

Each of the problems with methanol blends has numerous solutions, but it is unclear at present which will be the most effective at increasing motor fuel supplies at the least cost to consumers. Additional work is needed to clarify this matter.

Methanol

In order to use methanol, carburetors suitable for methanol have to be installed on the engine or old ones modified. New engines designed for methanol could have higher compression ratios and burn leaner fuel mixtures, leading to a potential 20-percent improvement in thermal efficiency .34 35 As with ethanol, slightly smaller engines could be used because of the greater power associated with the higher compression ratio, which could provide still greater efficiency improvements.

Another possible approach with methanol is to decompose the alcohol into carbon monoxide (CO) and hydrogen in the carburetor. This gas mixture is then used to fuel the engine. Exhaust heat from the engine is used to fuel the decomposition; and the CO-hydrogen mixture contains 20 percent more energy than the methanol from which it came. This offers the possibility of improving the engines thermal efficiency by 20 percent, but it is too soon to know whether this potential increase can be achieved in practice.

Methanol can cause gasoline fuel injection pumps to fail, due to its low lubricity. " Other tests indicate that methanol combustion corrodes cast iron piston rings and may affect normal lubricating oils, particularly in very cold weather starting. " However, in actual engine and vehicle tests in warm weather conditions, methanol has not been found to cause premature engine wear. 38

Below about 400 F, methanol-fueled engines can experience starting problems, due to the same factors that affect ethanol-fueled vehicles. As with ethanol, special equipment and/ or blending of volatile hydrocarbons in the fuel will be needed to enable cold starting.

Summary

Ethanol-gasoline blends are currently being marked commercially, and methanol blends (with a cosolvent) are being test marketed. In addition, automobiles fueled with straight ethanol are being used in Brazil and extensive tests with methanol-fueled vehicles are underway. Nevertheless, because the alcohols are not fully compatible with the existing liquid fuels delivery system and automobile fleet, some initial difficulties in using alcohol fuels

[30] A. W. Crowley, et al , "Methanol-Gasoline Blends Performance in Laboratory Tests and Vehicles, " *Inter Industry Emission Control Program-2, Progress* Report No. *1* (Society of Automotive Engineers, 1975)

● Nevertheless, one test of automobiles operating on a phase-separated blend showed fewer drivability problems than would have been expected [31]

"Stamper, "50,000 Mile Methanol/Gasoline Blend Fleet Study," op. cit.

[32] B C Davis and W H Douthut, "The Use of Alcohol Mixtures as Gasoline Additives, " Suntech, Inc , Marcus Hook, Pa , presented at 1980 National Petroleum Refiners Association Annual Meeting, March 1980.

"Stamper, private communication, op cit

[34] W J Most and J P Longwell, "Single Cylinder Engine Evaluation of Methanol-Improved Energy Economy and Reduced NO_x," SAE paper No 750119, February 1975

[35] Pefley, et a l, op cit

[36] J C Ingamells and R H Lindquist, "Methanol as a Motor Fuel or a Gasoline Blending Component, " SAE paper No 750123, Automotive Engineering Congress and Exposition, Detroit, Mich , February 1975

[37] E.C. Owens, "Methanol Effects on Lubrication and Engine Wear," in *Proceedings of the International Symposium on Alcohol Fuel Technology, Methane/ and Ethanol,* Wolfsburg, West Germany, Nov. 21-23 1977.

[38] Pef lcy, et al , op cit

are to be **expected.** These problems should disappear with time, however, as more experience is gained at handling and using the alcohol fuels and as older automobiles are replaced with vehicles designed **for use with these fuels.**

For ethanol the preferred use probably is as an octane-boosting additive to gasoline because of the energy saved by allowing refiners to produce a lower octane gasoline. The situation with methanol is less clear because of the greater difficulties associated with methanol **blends and the possible need for cosolvents. The use of methanol both** in blends and as a straight fuel is currently being pursued.

Diesel Engines

Alcohols have only limited volubility in diesel fuel, making diesel-alcohol blends impractical at present. * If "ignition accelerators"* * are dissolved in the alcohols to enable them to ignite in diesel engines, they can be used as a replacement for diesel fuel, but the **fuel metering system would have to be modified to provide** the full range of power for which the engine was designed and some provisions made for the decreased lubricity of the alcohols.

Alternatively, the alcohols can be used in dual fuel systems, i.e., where the alcohol and diesel fuel are kept in separate fuel tanks and separate fuel metering systems are used. The two main possibilities are fumigation and dual injection. In a fumigation system, the alcohol is passed through a carburetor or injected into the air intake stream and the alcohol-air mixture replaces the intake air. In dual injection, each fuel is injected separately into the combustion chamber.

Most diesel engines are speed governed, i.e., more or less diesel fuel is injected automatically to maintain a constant engine speed for a given accelerator setting. **If alcohol is fumigated into the cylinder, the diesel injection decreases automatically** when the engine is not at full power to compensate for the additional power from the alcohol. At full power, the alcohol will give the engine additional power. Consequently, once a fumigation system is installed, alcohol usage is optional, since the engine will run normally without the alcohol present, but the higher power at full power can cause additional engine wear if the engine is not designed for this power. Alternatively, the diesel injection can be modified to allow less fuel to be injected, but it would have to be returned to its original state when alcohol is not being used. Dual injection systems also can be designed to run with or without alcohol, but the injection controls would probably be more complicated.

If the fuel systems are separate, alcohol containing up to 20 percent water probably can be used. However, the diesel engines must be modified to accommodate the alcohols. The modifications for alcohol fumigation are relatively simple and can be performed for an estimated $150 if, for example, a farmer does it himself and uses mostly spare parts. " Costs could range up to $500 to $1,500 if installed by a mechanic using stainless steel fuel tanks and all new parts.[40] Cost estimates for modifying engines for dual injection are not available, **however, but** would be more expensive. In either case the long-term effects, such as possibly increased engine wear, are unknown at the present time.

Fumigation systems will generally be limited to 30 to 45 percent ethanol or about 20 percent methanol, because evaporation of the alcohol cools the combustion air and the cooling from higher concentrations is sufficient to prevent the diesel fuel from igniting. However, consid-

*Emulsions are possible, but still in the R&D phase

** Although alkyl nitrates have generally been used as ignition accelerates, sunflower seed oil and other vegetable oils have been suggested for biomass-derived ethanol

[39] Pefley, et al, op cit

[40] Ibid

erably higher proportions of alcohol can be used with dual injection systems.[41]

In fumigation systems, some tests have shown thermal efficiency increases of up to 30 percent for certain combinations of alcohol and diesel fuel.[42] Other tests[43] showed slight increases (5 percent) in thermal efficiency when the engine is at two-thirds to full load, while there are large decreases (25 percent) in efficiency at one-third full load. Similar ambiguities exist for dual injection systems.[44] These differences in efficiency are due to differences in engine tuning and design. An accurate determination is not available at present, but it is unlikely that there will be significant differences in the thermal efficiencies of engines optimized for the respective fuels.

41 F, F Pischinger and C Havenith, "A New Way of Direct Injection of Methanol in a Diesel Engine," in *Proceedings of the Third International Symposium on Alcohol Fuels Technology, vol. II*, Asilomar, Calif, May 1979

42 K Bro and P S Pederson, SAE paper No. 770794, September 1977

43 K D Barnes, D B Kittleson, and T E Murphy, SAE paper No 750469, Automotive Engineering Congress and Exposition, Society of Automotive Engineers, Detroit, Mich, February 1975.

Considerable uncertainty exists about the thermal efficiencies that can be obtained in practice if, for example, tractors are converted to alcohol use. Assuming, however, that the thermal efficiency does not change, 1 gal of ethanol would replace 0.61 gal of diesel fuel, and 1 gal of methanol would replace 0.45 gal of diesel fuel.

44 E Holmer, "Methanol as a Substitute Fuel in the Diesel Engine," In *Proceedings of the International Symposium on Alcohol Fuel Technology, Methanel and Ethanol*, West Germany, November 1977

Environmental Impacts of Automotive Use of Biomass Fuels

The use of alcohol fuels and gasoline-alcohol blends in automobiles will have a number of environmental impacts associated with changes in automotive emissions as well as differences in the toxicity and handling characteristics of the fuel alternatives. The potential changes in automotive emissions have been identified as the impact of major concern and are treated in the greatest detail in this discussion.

Air Pollution—Spark Ignition Engines

Predictions of emissions changes can be based on a combination of theoretical considerations, laboratory tests, and field measurements. Unfortunately, the results of the emissions tests that have been completed to date are varied and confusing. Difficulties with using these results for predicting emissions changes include:

- Tests are rarely comparable because of different base fuels (gasolines), fuel mixtures, automobiles, state of "tune," driving cycle, etc.
- **In some important tests, methodological problems may seriously weaken the derived conclusions.** For example, the Environmental Protection Agency's (EPA) 1978 tests of "gasohol" (10 percent ethanol blend) included some vehicles that either operated too "fuel-rich" initially (four vehicles) or exceeded the nitrogen' oxide (NO_x) standard on indolene (two vehicles).[45] If these noncompliance vehicles are dropped from the test sample, the changes caused by using gasohol are less than test-to-test variability in exhaust emissions for the same vehicle.[46]
- Test results have generally been obtained from laboratory engines or, in testing alcohol blends, from relatively unmodified automobile engines. A strategy that provided reliable and plentiful supplies of alcohol fuels would presumably be ac-

45 *Characterization Report: Analyses of Gasohol Fleet Data to Characterize the Impact of Gasohol on Tailpipe and Evaporative Emissions* (Washington, D C Technical Support Branch, Mobile Source Enforcement Division, Environmental Protection Agency, December 1978)

46 Wiplore K Juneja, et al, "A Treatise on Exhaust Emission Test Variability," *Society of Automotive Engineers*, VOl 86, paper 770136, 1977

companied by design changes that would take advantage of the different properties of these fuels. Thus, extrapolations from current test data may be overly pessimistic, at least for the long run.

Aside from test results, emission changes can be explained in great part by the dependence of emissions on the operating conditions of the engine. Emissions of CO, HC, NO_x, and aldehydes are strongly influenced by the "equivalence ratio Φ" (stoichiometric A/F ratio/actual A/F ratio) and the emission control system (none, oxidation catalyst, etc.). Figure 37 shows how CO, HC, NO_x, and aldehydes are likely to vary with Φ.

Both methanol (6.4:1) and ethanol (9:1) have lower stoichiometric A/F ratios than gasoline (14. s: I). Thus, blends of either alcohol fuel result in lower equivalence ratios ("leaner" operation) if no changes are made in the fuel metering devices. Examining figure 37, emissions changes can be predicted qualitatively by observing that adding alcohol pushes the equivalence ratio to the left. For an automobile normally operating "lean," CO may be expected to remain about **the same,** HC remain the same or increase slightly, and NO_x decrease. For out-of-tune automobiles, which usually operate in a "fuel rich" mode, CO and HC may be expected to decrease while NO_x increases. Vehicles equipped with three-way catalysts have feedback-controlled systems that operate to maintain a predetermined value of Φ and thus should be less affected by the blend leaning effect of the alcohol fuels. However, this feedback system is usually overridden during cold starting to deliver a fuel-rich mixture; during this time period, HC and CO are more likely to decrease and NO_x to increase with alcohol fuels. Also, catalysts with oxygen sensors can be fooled into adjusting to leaner operation because the exhaust emissions from alcohol blends oxidize faster than gasoline-based exhausts and drive down the oxygen level in the exhaust stream (giving the appearance of overly fuel-rich operation);[47] this should also tend to decrease HC and CO and increase NO_x emissions when alcohol blends are used in vehicles equipped with such catalysts.

Table 64 provides a summary of the type of emissions changes that may be expected by combining knowledge of test results and the

[47] **Cratch, op cit**

Table 64.–Emission Changes (compared to gasoline) From Use of Alcohol Fuels and Blends

Pollutant/fuel	Methanol	Methanol/gasoline	Ethanol	Ethanol/gasoline "gasohol'
Hydrocarbon or unburned fuels	About the same or slightly higher, but much less photochemically reactive, and virtual elimination of PNAs; can be catalytically controlled	May go up or down in unmodified vehicles, unchanged when Φ remains constant. Composition changes, the, and PNAs go down. Can be controlled. Higher evaporative emissions	Not very much data, should be about the same or higher but less reactive. Expected reduction in PNA	May go up or down in unmodified vehicles, about the same when Φ remains constant; composition may change, expected reduction in PNAs. Evaporative emissions up
Carbon monoxide	About the same, slightly less for rich mixtures; can be catalytically controlled; primarily a function of Φ	Essentially unchanged if@ remains constant, lower if leaning is allowed to occur	About the same, can be controlled ; primarily a function of Φ	Decrease in unmodified vehicles (i.e., leaning occurs), **about the** same when Φ remains constant
Nitrogen oxides	1/3 to 2/3 less at same A/F ratio, can be lowered further by going very lean; can be controlled	Mixed; decreases when is **held** constant, but may increase from fuel "leaning' effect in unmodified vehicles	Lower, but not as low as with methanol; can be controlled	Slight effect, small decrease when Φ is held constant, but may increase or decrease further from fuel "leaning' effect in unmodified vehicles
Oxygenated compounds	Much higher aldehydes, particularly significant with precatalyst vehicles	Aldehydes increase somewhat, most significant in precatalyst vehicles	Much higher aldehydes, particularly significant with precatalyst vehicles	Aldehydes increase, most significant in precatalyst vehicles
Particulate	Virtually none	Little data	Expected to be near zero	Little data, no significant change expected
Other	No sulfur compounds, no HCN or ammonia	Unknown	No sulfur compounds	No data

SOURCE Office of Technology Assessment

theoretical model discussed above. The most significant changes, and their environmental implications, are:

- **Substantial reductions in reactive HC and NO_x exhaust emissions with 100 percent (neat) methanol and, to a lesser extent, ethanol.—** Although HC emissions are expected to remain approximately the same with alcohol fuel use at the same *,[48 49] the reactivity of these emissions is much lower than that of gasoline-based HC emissions. Reductions in reactive HC and NO_x should reduce photochemical smog formation, although predictions of the magnitude of these effects are difficult.
- **Increase in aldehyde emissions with neat alcohols and blends.—** Use of pure alcohol fuels yields several-fold increases in aldehydes,[50 51] whereas blends increase aldehyde emissions to a lesser extent. Because catalytic converters are effective in removing aldehydes, catalyst-equipped vehicles tend to have low aldehyde emissions whether or not alcohol is used;[52 53] the major problem lies with cars not equipped with catalysts.

  Aldehydes cause eye and respiratory irritations and are photochemically reactive. Despite this, aldehydes are not specifically regulated in automobiles, and the most abundant aldehyde in automotive emissions–formaldehyde – is not detectable with conventional HC measuring instrumentation. Aldehyde increases may somewhat negate the positive effects of reductions in emissions of HC as well as in NO_x emissions from alcohol use. The magnitude of the potential impacts, however, is not well understood.
- **Substantial. reductions in particulate emissions if neat alcohol fuels are used. —** Use of neat alcohol fuels may reduce particulate emissions virtually to zero. This is particularly significant when the fuel substituted for is leaded gasoline; particulate emissions from autos using leaded gasoline are on the order of 0.6 g/mile on the Federal emission test cycle, and most of the particles are toxic (mostly lead by weight, with polynuclear aromatic (PNA) compounds adsorbed on their surfaces) and in the inhalable size range (whereas particulate emissions from autos using unleaded gasoline are on the order of 0.2 g/mile on the same test cycle, are about 90-percent controllable with catalytic converters, and are composed mainly of carbon particles.[55]
- **Substantial reductions in PNA compounds with neat alcohols and blends. —** PNA compounds emitted in small quantities in automobile exhausts are toxic and carcinogenic. 56 Methanol and methanol blends appear to provide substantial reductions in these emissions (methanol exhaust contains only about 1 percent of the PNA compounds observed in gasoline exhaust),[57] which may be of some significance in reducing the cancer hazards of urban air pollution. Ethanol and ethanol blends may be expected to provide similar effects, but this has not yet been verified.

[48] David L Hilden and Fred B Parks, "A Single Cylinder Engine Study of Methanol Fuel – Emphasis on Organic Emissions," Society of Automotive E ngineers paper No 760378, presented at the Automotive Engineering Congress, Dearborn, Mich , Feb 23-27, 1976

"Samuel O Lowry and R S Devoto, "Exhaust Emissions From a Single-Cyl inder Engine Fueled With Gasoline, Methanol, and Ethanol, " *Combustion* Science *and Technology,* vol 12, Nos 4, 5, and 6, 1976, pp 177-82

[50] W Lee and W Geffers, "Engine Performance and Exhaust Emission Characteristics of Spark Ignited Engines Burning Methanol and Methanol-Gasoline Mixtures, " Volkswagen Research and Development Division, Wolfsburg, West Germany, presented at AICLE meeting, Boston, Mass , September 1975

"Comparative Automotive Engine Operation When Fueled With Ethanol and Methane/ (Washington, D C Alcohol Fuels Program, Alternative Fuels Utilization Program, Department of Energy, May 1978)

[52] J R Allsup, "Experimental Results Using Methanol and Methanol/G asoline Blends as Automotive Engine Fuel, " Bartlesville Energy Technology Center, No B9RC/R1-76/15, January 1977

[53] J R Allsup and D B Eccleston, "Ethanol/Gasoline Blends as Automotive Fuels, " Bartlesville Energy Technology Center, draft No 4

[54] R E Sampson and G S Springer, "Effects of Exhaust Gas Temperature and Fuel Composition on Particulate Emission From Spark Ignited Engines, " *Environmental Science and Technology,* vol *7, No 1,* January 1973

[55] I bid

"American Petroleum Institute, "API Toxicological Review Gasoline, " 1967

[57] *On the Trail of New Fuels – Alternative Fuels for Motor Vehic/es* (Bonn, West Germany Federal Ministry for Research and Technology, 1974), translated by Addis Translation International

Air Pollution—Diesel Engines

Very little data is available to allow the prediction of emission changes from the use of alcohol fuels and blends in diesel engines. Predictions of some limited reliability may be made from the small number of tests, extrapolation from spark ignition tests, and knowledge of diesel characteristics.

The major environmental reason why alcohol fuels appear to be attractive for diesels is their ability to burn without producing particulate emissions. Domestic manufacturers are having problems meeting the proposed EPA particulate standard of 0.6 g/mile. Particulate emissions from diesel engines are 50 to 100 times those from gasoline engines[58] and may contain more PNA; particulate reductions thus appear to be especially attractive environmentally.

HC emissions from diesels are more photochemically reactive than automobile HC emissions. Although a switch to alcohol fuels by itself will have an uncertain effect on uncontrolled emissions, the elimination of particulate emissions may allow the use of oxidation catalysts to improve HC control (because particulates otherwise would plug up the catalyst).[59]

If alcohol fuels behave in diesels in a manner similar to their behavior in spark ignition engines, they should cause NO_x emissions to decrease and aldehydes to increase. CO levels have been observed in tests to double their originally low values when shifting from diesel fuel to alcohol;[60] however, this is thought to be a correctable problem with the fuel injection systems.

Alcohol fuels have poor ignition capabilities when injected into the compressed and heated air in a diesel engine. To counteract this difficulty, ignition accelerating agents containing nitrates can be added to the fuel to provide an ignition source for the alcohol. There appears to be some potential for the formation of hydrogen cyanide or ammonia in the combustion process when these additives are used. Laboratory testing will be necessary to verify the existence of this effect.

Emission characteristics of mixed fuel operation with alcohol and diesel fuels depend on the method of introducing the alcohol into the combustion chamber.

When the alcohol is mixed with the intake air (fumigation), the following changes have been observed to occur:[61]

- increase **in HC** emissions and aldehydes,
- little change **in CO,**
- **increase or decrease in NO_x, and**
- **decrease** in particulate.

The emissions effects of other fuel systems are poorly understood.

Occupational Exposures to Fuels and Emissions

In general, the effects of gasoline and gasoline-based emissions are more acute, in an occupational setting, than those of methanol and ethanol. For example:

- Short-term exposure to gasoline is considered more poisonous, tissue disruptive, and irritative than methanol when effects of eye contact, inhalation, skin penetration, skin irritation, or ingestion are considered.[62] Effects of the more severe (ingestion) exposures to methanol are generally reversible, although in some extreme cases there can be irreversible effects on the central nervous system, optic nerve end, and heart. 63

" K J Springer and T M Baines, "E missions From Diesel Versions of Production Passenger Cars, *Society* of A *utomotive Engineers Tran/at/ens,* vol *86,* sec 4, paper No 770818, 1977

" M Amano, et al , "Approaches to Low Emission Levels for Light-Duty Diesel Vehicles, " Society of Automotive Engineers paper No 760211, February 1976

[60]W F Marshall, *Experiments* With *Novel* FLIP/5 for *Diesel Engines* (Bartlesville, Okla Bartlesville Energy Technology Center, Department of Energy, February 1978), II ERCITPR-7718

" B S Murthy and L G Pless, "Et ffectiveness of Fuel Cetane Number for Combustion Control in Bi-Fuel Diesel E ngine," *Journal of the Institution 01 Engineers [India),* vol *45, No 7,* pt ME 4, March 1965

[62]N V Steer, ed , *Handbook of Laboratory Safety* (Cleveland, Ohio Chemical Rubber Co , 1971)

[63]M N Gleason, et al , *Clinical Toxicology of Commercial Poisons,* Williams and Williams

- The effects of both acute and chronic exposure to ethanol are considered to be much less disruptive than methanol and, therefore, gasoline.
- The automotive exhaust emissions that are most dangerous in an enclosed space — such as a garage without adequate ventilation —are CO from gasoline and CO and formaldehyde from methanol. If a fleet of methanol-powered cars is compared directly to a fleet of gasoline-powered cars, CO will be the most dangerous pollutant (and equally dangerous for both fleets, because methanol should not substantially change CO emissions)—so long as three-way catalysts are used. Without catalysts, formaldehyde emissions could be more dangerous than CO **in the methanol-powered fleet.**

  It is interesting to observe that, for the catalyst-equipped methanol fleet, formaldehyde will act as a "tracer" for CO; if eye and respiratory irritation from formaldehyde becomes acute, this will be an almost sure sign that CO is at dangerous levels.

Safety Hazards

The risks of fire and explosion appear to be lower with alcohol fuels than with gasoline, although evidence is mixed:

- gasoline has a lower flash point and ignition temperature and is more flammable and explosive in open air than either ethanol or methanol,[64]
- alcohols are the greater hazard in closed areas,[65]
- higher electrical conductivity of alcohol lessens danger of spark ignition,
- high volubility in water makes alcohol fires easier to fight than gasoline fires, and
- alcohol fires are virtually invisible, adding **to** their danger (but addition of trace materials could overcome this drawback).

Alcohol blends will be similar to gasoline but they may be more ignitable in open spaces and less ignitable in **closed containers when** the blends have higher evaporation rates than the pure gasoline. Diesel fuels and diesel alcohol emulsions are considered to be safer than gasoline or alcohol fuels.[66]

Environmental Effects of Spills

To the extent that domestic alcohol production substitutes for significant quantities of imported oil, a reduction in fuel transportation and a consequent reduction in spills can be expected. If alcohol is shipped by coastal tanker, the possibility of large alcohol spills is a realistic one, and the effects of such spills should be compared to the effects of oilspills.

Alcohol fuels appear to be less toxic than oil in the initial acute phase of the spill and have fewer long-term effects. Except in areas where alcohol concentrations reach or exceed 1 percent, the immediate effects of a spill should be minimal. For example, a concentration of about 1 percent methanol in seawater is tolerated by many common components of intertidal, mud-flat, and estuarine ecosystems unless the alcohol is contaminated with heavy metals.[67] In contrast, crude oil contains several highly toxic water soluble components that can be damaging at low concentrations. Furthermore, alcohols are extremely biodegradable— toxic effects may be eliminated in hours —whereas the effects of heavy fuel oils can last for years.

Hazards to the Public

The widespread distribution and use of alcohol fuels will result in the public facing the same potential dangers as exist in the occupational environment. A true assessment of ethanol and methanol public health risks must incorporate an analysis of probable exposure, however, and such an analysis is likely to show that both alcohol fuels may have considerably

[64]*CRC Handbook of Laboratory Safety,* **op** cit
[65]Ibid

[66]M E LePera, **"Fine Safe Diesel Emulsions, "Conference** *on Transportation Synfuels,* **sponsored** by **the Department of Energy, San Antonio, Tex , November 1978**

[67]P N D'Eliscu, **"Biological Effects of Methanol Spills Into Marine, Estuarine, and Freshwater Habitats, " in** *Proceedings of the International Symposium on Alcohol Fuel Technology, Methanol and Ethanol,* **Wolfsburg, West Germany, Nov 21-23, 1977**

greater potential than gasoline to harm the public. For example, although methanol and gasoline are comparably toxic upon ingestion, methanol has a long history of improper ingestion and gasoline does not. Ethanol is even more likely to be improperly used, and the ethanol used for motor fuel blending will be contaminated with dangerous toxic chemicals. Although vile tasting and smelling denaturants may be added to fuel ethanol to discourage improper use, enterprising individuals are likely to try to filter out these additives. Also, fuel ethanol may be diverted to consumption before these denaturants are added. The probability of such diversion will be especially high if small, onfarm ethanol stills are widely used.

A careful risk assessment of ethanol and methanol fuels and blends could identify and quantify these types of risks and would be invaluable both in setting priorities **for research and** in devising risk mitigation strategies that must accompany promotion of alcohol fuel use. Such an assessment has not as yet been conducted by DOE.

Gas Turbines

Alcohol fuels can be used readily in gas turbine generators used to generate peakload electric power. The fuel metering system has to be modified to meter the larger volumes of alcohols necessary to maintain the same power output and to accommodate the lower lubricity of alcohols relative to light fuel oil. These modifications are minor. In some cases, however, the alcohols may attack the turbine blades or other metal parts and the modifications needed **to use alcohol fuels** would be considerably more expensive.

If alcohol fuels are used, care must be taken to ensure that no salts are dissolved in the alcohols by, for example, contamination with seawater during barge transport. The salts could greatly reduce the life of the turbines.

The thermal efficiency of a gas turbine is determined by the ratio of the pressures at the turbine inlet and outlet. This ratio is limited by the combustion temperature. The alcohols have slightly lower combustion temperatures and should allow higher efficiencies than with light fuel oil in redesigned turbines. In unmodified turbines, the thermal efficiency of the alcohol fuels is about the same (within ± 2 percent) as for light fuel oils.[68,69] Thus, 1 gal of ethanol would replace 0.67 gal of light oil and 1 gal of methanol would replace 0.48 gal of light fuel oil.

Currently about 0.25 Quad/yr of oil and 0.2 Quad/yr of natural gas are consumed **for peakload electric generation.[70] This represents about 6 percent of the electricity generated** in the United States. Use of alcohol fuels here would save about 0.2 trillion ft^3 of natural gas per year and about 130,000 bbl/d of light distillate oil.

Air Pollution Effects of Alcohol Fuel Use in Gas Turbines

Although alcohol fuels have been tested in gas turbines and the resulting emissions levels have been measured, there is some doubt as to whether those levels represent true indicators of emissions to be expected from an optimized system. For example, methanol use in an automotive gas turbine produced a tenfold increase in HC emissions in one test,[71] but it is quite possible that more optimal design of the fuel injection nozzles could lower these values considerable y.

[68] I W Huellmantel, S G Teddle, and D C Hammond, Jr, "Combustion of Methanol in an Automotive Gas Turbine," in *Future Automotive Fuels*, JM Colucci and N E Gallapoulous, ed (New York Plenum Press, 1977)

[69] P M Jarvis, "Methanol as Gas Turbine Fuel," presented at the 1974 Engineering Foundation Conference, *Methanol as an Alternate Fuel*, Henneker, N H, July 1974

[70] Adelman, et al, op cit

[71] C W Lapointe and W L Schultz, "Comparison of Emission Indices Within a Turbine Combustor Operated on Diesel Fuel or Methanol," Society of Automotive Engineers paper No 710669, June 1971

The most significant emission change should be a substantial drop in NO_x emissions, which are typically quite high in gas turbines. Methanol has achieved 76-percent reductions in NO_x emissions in large turbines because it has a significantly lower combustion temperature than distillate fuels.[72] Ethanol, which has a combustion temperature intermediate between methanol and distillates, should achieve somewhat smaller reductions.

[72] Jarvis, op cit