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POTENTIAL SOURCES OF NON-PETROLEUM BASED ALCOHOL FUELS
FOR VEHICULAR FLEET TESTING

October 1979

Work Performed Under Contract No. EX-76-C-01-2098

Mueller Associates, Inc.
Baltimore, Maryland

MASTER

U.S. Department of Energy

Solar Energy

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BASED ALCOHOLS FOR VEHICULAR FLEET TESTING

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For

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Washington, D.C. 20585

Under Contract No. EX-76-C-01-2098

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TABLE OF CONTENTS

	<u>PAGE</u>
FOREWORD	ii
INTRODUCTION	1
FUEL VOLUME NEEDS	2
POTENTIAL PROCESSES FOR OBTAINING ALCOHOLS	3
• Methanol From Coal	3
• Methanol From Wood and Other Biomass Resources	7
• Ethanol From Agricultural Biomass	8
POTENTIAL COMMERCIAL FACILITIES FOR ALCOHOL PRODUCTION	9
• Methanol	9
• Ethanol	12
CONCLUSIONS	16
REFERENCES	18

FOREWORD

This report was prepared by Mueller Associates, Inc., Consulting Engineers, Baltimore, Maryland (under Contract EX-76-C-01-2098) for Mr. E. Eugene Ecklund Chief, Alternative Fuels Utilization Branch, Office of Transportation Programs, U.S. Department of Energy.

In 1977, the American Energy Research Company undertook a thorough assessment of alcohol availability for DOE-sponsored vehicle fleet tests. That assessment resulted in a report titled, "Sources of Alcohol Fuels For Vehicle Fleet Tests" (published as DOE report number HCP/M2693-01, January, 1978). After the report's publication, the Department of Energy desired a brief summary of it, inclusion of more recent information on the availability of fermentation ethanol, and an estimate of the alcohol fuel volume required to support vehicle fleet tests. Accordingly, in preparing this report the primary reference utilized was the above mentioned report by the American Energy Research Company. Because of the extensive use of this document, it is not cited directly in the reference section. Other reference materials are listed in accordance with common documentation practices. Alcohol fuel volume calculations were performed by Mueller Associates.

Richard L. Rentz

Thomas J. Timbario

INTRODUCTION

One major objective of the Department of Energy's (DOE) development program for the transportation sector is to identify and aid the commercialization of alternative fuels as a supplement to or replacement for current petroleum-based fuels. Various studies and/or demonstrations have been performed to establish the technical feasibility of this concept. However, in any alternative fuel/engine program proof of performance is paramount. Once the technical problems have been solved, reliability fleet testing is necessary. Projected tests will involve sizeable vehicle fleets to provide performance data throughout a cross-section of geographical and climatic conditions.

The first such alternative fuel test fleet will employ alcohol/gasoline blends and is expected to take place between October 1979 and the end of FY 1982; subsequent fleet testing of straight alcohols is also planned (over a time span of six years, tentatively scheduled for start-up in FY 1982). The alcohols employed are expected to be methyl alcohol (methanol) and ethyl alcohol (ethanol), both individually and as a mixture of the two. Methanol and ethanol, the two simplest members of the alcohol family, are most often considered as alternative automotive fuels partially because they can be fabricated from a large variety of non-petroleum feedstocks. They are also generally less expensive to produce than higher order alcohols. This report addresses the prospects for obtaining these alcohols from non-petroleum/non-natural gas feedstocks in sufficient quantities during the time frame required by DOE for reliability fleet tests. The cost of the synthesized alcohol is not of overwhelming importance to the reliability fleet testing program but is, of course, a critical factor to commercialization.

Methanol and ethanol can be obtained from a number of sources. The more logical derivations of these fuels are as follows:

1. Methanol from domestic natural gas.
2. Imported methanol from natural gas and/or domestically produced methanol from imported natural gas which would otherwise be flared.
3. Methanol from coal, wood, or other non-petroleum resources.
4. Ethanol from petroleum products.
5. Ethanol from agricultural biomass.

From a technical viewpoint the source of feedstock is immaterial. However, for public relations and petroleum/natural gas conservation reasons it is highly desirable to supply the necessary methanol/ethanol from feedstocks other than petroleum and natural gas. Imported methanol (Item 2) aids conservation of the world petroleum supplies, but lacks the public relations impact of Items 3 and 5. Accordingly, this report is restricted to a discussion of the potential for obtaining alcohols from these non-petroleum/non-natural gas feedstocks.

FUEL VOLUME NEEDS

Although the initial fuel requirement for fleet testing might be as small as 10,000 gallons per year, it could easily increase many fold over the next several years. Since the DOE also plans to fleet test straight-alcohol-fueled vehicles, beginning in FY 1982, an analysis of neat alcohol fuel volume needs is also included.

The basic assumptions used to arrive at alcohol fuel volume requirements are a reference vehicular fleet fuel economy of fifteen miles per gallon (15 mpg) and an individual vehicle yearly mileage accumulation of 15,000 miles (15,000 mi/yr/veh). The fuel economy for neat alcohols was adjusted to reflect the heating values of the alcohols (lower heating values of 115,000

Btu per gallon for gasoline, 75,670 Btu per gallon for ethanol, and 56,560 Btu per gallon for methanol were utilized). For alcohol blends, an unadjusted and an adjusted fuel economy value was utilized. The results are as shown in Figure 1, indicating fuel volume requirements as a function of the number of fleet vehicles. The equivalent information is also presented in Table 1.

It should be pointed out that the individual volume requirements for ethanol and methanol are not at this time known since the specific fleet size has not yet been determined.

POTENTIAL PROCESSES FOR OBTAINING ALCOHOLS

The major non-petroleum/non-natural gas feedstocks for the manufacture of methanol and ethanol include coal, wood, municipal wastes, and agricultural biomass. Historically, methanol was originally produced from destructive distillation of wood (hence the pseudonym "wood alcohol"). At the present time, almost all methanol is chemically synthesized from carbon monoxide and hydrogen which were in turn derived from natural gas. Ethanol was originally produced from the yeast fermentation of agricultural carbohydrates. However, due to current economics most industrial ethanol is today derived from ethylene obtained from petroleum and natural gas products. Higher order alcohols are generally produced from petroleum, although other methods are possible. Since it has not, for several decades, been economical to produce industrial and fuel grade methanol from non-petroleum/non-natural gas feedstocks, facilities for the production of methanol for these purposes does not presently exist in the U.S. The situation for ethanol is only presently being altered.

o Methanol from Coal

From a resource availability standpoint, the U.S. is abundantly supplied with coal and this supply is more than adequate to support DOE fleet test fuel needs (for methanol).

*Based on equivalent fuel economy relative to gasoline (15 mpg).

**Based on fuel economy adjusted for heat values.

FIGURE 1, ALCOHOL FUEL VOLUME REQUIREMENTS FOR RELIABILITY FLEET TESTING VS. NUMBER OF TEST VEHICLES

NUMBER OF TEST VEHICLES	100	500	1,000	2,000	3,000	4,000	5,000
Neat Ethanol	148.1	740.7	1,481	2,963	4,444	5,926	7,407
Neat Methanol	194.2	970.9	1,942	3,884	5,825	7,767	9,709
Methanol or Ethanol-10%*	10	50	100	200	300	400	500
Methanol or Ethanol-20%*	20	100	200	400	600	800	1,000
Ethanol-10%	10.34	51.69	103.4	206.8	310.1	413.5	516.9
Ethanol-20%	21.39	10.7	213.9	427.8	641.7	855.6	1,070
Methanol-10%	10.51	52.56	105.1	210.2	315.3	420.5	525.6
Methanol-20%	22.14	110.7	221.4	442.8	664.2	885.6	1,107

*Based on equivalent gasoline fuel economy.

TABLE 1, YEARLY ALCOHOL FUEL VOLUME REQUIREMENTS FOR
RELIABILITY FLEET TESTING, 1000's OF GALLONS

In addition, the necessary coal-to-methanol technology is well developed (although no large-scale commercial endeavors have yet to be attempted in the U.S.) and the economics are improving. The manufacture of methanol from coal basically involves gasification of the coal, adjustment of the resulting hydrogen to carbon monoxide ratio, and reaction of these gases in a high pressure and temperature environment in the presence of a selective catalyst. A crucial step in this coal to methanol process is coal gasification. Of the dozens of processes for coal gasification, the Koppers-Totzek, Lurgi, Wellman-Galusha, Winkler, and Synthane (developed by the U.S. Bureau of Mines) processes, appear to be the most viable candidates for a coal to methanol plant.

In all five processes, the methanol conversion from the resultant gaseous products would presumably only utilize the low (150 to 300 Btu/SCF) and medium (300 to 700 Btu/SCF) coal gases. High quality (700 to 1000 Btu/SCF) gas should be more valuable as a supplement to natural gas supplies. Although the five processes differ from each other somewhat, the resulting synthesis gas is essentially the same and will not affect the composition of the crude methanol.

Methanol is produced from carbon monoxide and hydrogen according to the following reaction:

However, these two gases can also react in a number of other ways. When the end objective is to produce methanol, these other reactions are undesirable. When methanol synthesis is done in the presence of a selective catalyst and special temperature and pressure conditions, the formation of methanol predominates while other reactions are suppressed; an unselective catalyst may be used if a methyl fuel (containing higher order alcohols and possibly some alcohol derivatives) is the desired product. There are several commercial processes to produce methanol from synthesis gas. The original high pressure process utilizes a zinc-chromium oxide catalyst at 5000 psi and 570°F.

Medium pressure, low pressure, and "three-phase" processes also exist, but the vast majority of present methanol plants utilize the original high pressure process. The overall thermal efficiency of a coal to methanol plant is about 60 percent, which is roughly equivalent to the thermal efficiency for a natural gas to methanol plant.

Due to the relative insensitivity of the ultimate chemical composition of the product to the composition of the coal feedstock, and the abundance of U.S. supplies of coal, availability of supply should present no problem. With proper treatment, even high sulfur coals can satisfactorily be employed.

o Methanol From Wood and Other Biomass Resources

Biomass sources such as crops, forestry, and municipal wastes represent a large, renewable resource that is not presently being effectively utilized. Not only are much of these materials being wasted, but in some cases the disposal is becoming a serious problem. While, in principal, any light hydrocarbon can be partially oxidized to yield some methanol, for practical reasons only wood and municipal wastes are herein considered as potential near-term sources of methanol.

Methanol can be synthesized directly from the destructive distillation (i.e., pyrolysis) of wood. Although this was the original process, for economic reasons this process of methanol production is not currently practical in the U.S. Alternatively, methanol may be produced using wood gasification techniques (similar to coal gasification) followed by an adjustment of the hydrogen to carbon monoxide ratio and reaction of the gases in the presence of a catalyst. Pressures up to about 2500 psi are involved. The overall thermal efficiency via gasification is about 38 percent for a wood waste to methanol plant.

Methanol may also be produced from the conversion of methane obtained from the anerobic digestion of manure, sewage, or municipal wastes. Due to the volume of available feedstock,

transportation costs and other practical considerations, such sources are not considered to be significant prospects for supplying large quantities of methanol in the near future. These feedstocks could more likely produce a fuel grade methane gas.

o Ethanol from Agricultural Biomass

For centuries ethanol has been produced through the fermentation of fruits and grains. However, for the past few decades, it has been less expensive to produce (non-beverage) ethanol from ethylene derived from petroleum. With rapidly escalating oil prices this situation may change.

Large scale ethanol fermentation plants are well within existing technology. A wide range of feedstocks such as sugar beets, potatoes, corn, cheese whey, sugar, molasses, wheat, other grains, and biomass materials can be employed. Generally speaking, the higher the sugar or starch content of the feedstock the more suitable it is. About 14 lbs. of sugar are required to produce one gallon of ethanol. Ethanol can also be produced from cellulose materials (such as wood and agricultural wastes). This is accomplished by hydrolysis of the feedstock into sugars, which are then fermented and distilled into ethanol. An acid hydrolysis process has been used for some time to convert wood wastes into ethanol. There are also enzymatic hydrolysis processes for ethanol synthesis. Although technical work in these areas is progressing, they do not appear to represent viable possibilities for providing the necessary quantity of ethanol in the near future.

Various recent studies have indicated that ample land is available to grow quantities of grain and sugar crops large enough to supply significant quantities of ethanol through fermentation. However, costs for biomass-derived ethanol remain relatively high and sale of fermentation byproducts (distillers dried feed) to improve economics is a must. In addition, to operate economically, an ethanol from biomass plant would need a dedicated, constant supply of feedstocks on a year-round basis. Thus, dependence on crop products

through years of varying harvests would be risky. Extensive storage facilities may be one means of reducing the risk associated with this harvest dependency.

POTENTIAL COMMERCIAL FACILITIES FOR ALCOHOL PRODUCTION

As was previously mentioned, large scale facilities for fuel-dedicated alcohol production from non-petroleum/non-natural gas feedstocks do not presently exist in the U.S. for methanol and are only in a preliminary stage for ethanol. Since the industry is capital intensive, this creates an inertia which tends to discourage investments in new plants and processes. However, the cost and unreliability of foreign oil supplies has spurred considerable interest in the area of alternative fuels.

o Methanol

Coal-based methanol, due to its developed technology and abundance of feedstock supply, appears to be the most viable prospect for obtaining methanol from non-petroleum/non-natural gas resources. Although most proposed facilities are primarily intended to produce pipeline quality substitute natural gas (SNG), they will also yield a raw product which is suitable for methanol synthesis. Some coal gasification processes, such as the Lurgi-Rectisol process, also employ methanol in the gas cleanup system.

At remote locations (typical of many coal gasification projects) it is generally preferable to produce the necessary methanol on site. Should this be done, enough methanol for the entire test fleet project could be produced from only one plant.

Currently, there are four proposed coal gasification projects in the U.S. which appear to offer potential for supplying the necessary quantities of methanol, although not until late in the fleet test project (at best). These are:

1. American Natural Resources Company, Tenneco, Peoples Natural Gas Company, Columbia Transmission Corporation and Transcontinental Gas Pipelines Corporation (collectively known as the Great Plains Coal Gasification Associates) in the Beulah-Hazen area of Mercer County, North Dakota.
2. Pacific Lighting Corporation and Texas Eastern Transmission Corporation at the Four Corners area, New Mexico.
3. El Paso Natural Gas Company at the Four Corners area, New Mexico.
4. Panhandle Eastern Pipe Line Company in Converse County, Wyoming.

Of the four plants the one closest to construction is the Great Plains Coal Gasification Associates project. This project is awaiting the final decision by a Federal Energy Regulatory Commission (FERC) law judge concerning their method of financing. The Pacific Lighting project has cancelled plans for constructing at the New Mexico site and has obtained leases for coal and water rights at a new site in Wyoming. The El Paso project is considering a partnership with a West German firm and is expected to file a new application during 1979. The Panhandle Eastern project is in a holding pattern and no filing has been made with FERC. [1]* All four of the above projects utilize the Lurgi gasification process in conjunction with the Lurgi-Rectisol gas cleanup process. The latter process requires methanol. One project, that of the American Natural Resources Company, et al., has already made the decision to produce their own methanol on site. The plant is designed to produce 137.5 million cubic feet of SNG per day. American Natural Resources Company Engineers have estimated that their gasifier, oxygen and steam capacities, and coal handling system all have enough excess capacity to provide as much as 50,000 gallons of additional methanol per day (which is more than sufficient to supply the entire fleet test project).

*Numbers in brackets refer to references at the end of this report.

The gas cooling system appears to be the only questionable subsystem which might have to be enlarged. Company officials have indicated their interest in supplying the necessary methanol for the DOE's fleet test project.

However, none of these proposed plants offers much hope of being on stream before 1985-86.^[2]

Significantly, there are several private ventures examining the possibility of producing methanol from coal explicitly for fuel purposes. The Santa Fe Railroad and an oil interest are examining the feasibility of a methanol from coal plant to be located in New Mexico. This plant could be on-stream by 1986.^[2] Also, the Southern California Edison and the Pacific Gas and Electric Companies are examining the concept of converting Alaskan coal into methanol for shipment to Southern California markets. Start-up of this plant could also be by 1985-86.^[2] There is commercial interest in constructing a methanol plant in West Virginia utilizing gob (waste produced during coal mining) as the feedstock. Start-up could be by 1984-85.^[2] Wentworth Brothers are investigating the establishment of a lignite to methanol plant in North Dakota as well as an Alaskan coal to methanol plant; construction could begin in a couple of years.^[2] Additionally, Conoco Coal Development Company expects to assemble a small consortium of companies (should the project proceed) to finance the construction of a commercial coal-to-methanol plant capable of producing about 3,000 tons per day of methanol. Such a plant would take four and a half years to build.^[3] Because of the long lead-time required for plant construction and current lack of construction/financial commitments, none of these projects can be depended upon to supply the quantities of methanol needed for the vehicular fleet test project within the required time frame.

The possibility of obtaining a sufficient supply of methanol from the destructive distillation of wood in the near future is low. There are presently no facilities in the U.S. either existing or planned that are large enough to supply all of the methanol required for fleet testing. However, it may be possible to have one or more small scale, Government sponsored, wood (biomass) gasification facilities on-stream in several years. [4]

Various projects exist for converting manure or municipal wastes into methane (which could then be synthesized into methanol). Cattle feedlots, sanitary landfills, and municipal wastes serve as sources for the necessary feedstock. However, these projects are generally of a small scale, are localized near specific feedstock supplies, and are probably best suited as sources of gaseous fuels. They are accordingly not considered as viable possibilities for a methanol source.

o Ethanol

Several possibilities exist for supplying fermentation ethanol to satisfy the DOE's fleet test needs.

The Aerospace Corporation recently studied the potential of the U.S. distilling industry as a source of ethanol for the DOE fleet test project. The report concluded that only three plants are presently capable of producing 200° proof ethanol and the potential for expansion is small. The 190° proof ethanol grade has been shown to be an unsatisfactory automotive fuel blend component. As a result, today's technology for vehicular applications (especially for alcohol/gasoline blends) centers on the utilization of 200° proof or anhydrous (water free) ethanol. Adding dehydration equipment to existing 190° proof plants for upgrading ethanol to 200° proof is possible, but it may take one-to-two years to achieve this conversion. Reactivation and upgrading of several idled plants is also possible, however, it may be unreasonable to expect the private sector to expand/upgrade/re-open production facilities unless a continuing and profitable market for the

expanded ethanol production is assured. There is excess capacity within the Kentucky bourbon industry (bourbon production requires utilization of high quality grains and thus would require that bourbon be produced separately from fuel grade ethanol), but Government financing may be needed for new equipment (including waste treatment facilities) in the smaller plants. For producers, market and profit assurances would probably be necessary.^[5]

Several of the major industrial and/or beverage suppliers of ethanol, to some extent, have shifted to producing ethanol for fuel use. Archer Daniels Midland Company is converting its eighteen million gallon per year fermentation plant at Decatur, Illinois from beverage to fuel ethanol production.^[6] Georgia-Pacific Corporation's pulp, paper, and chemical complex in Bellingham, Washington is currently capable of producing from waste products more than two million gallons of 200° proof ethanol annually (Georgia-Pacific was the supplier of ethanol for the state of Nebraska's two million mile Gasohol fleet test program and is supplying the state of California with ethanol for a program mandated by State Law).^[7] Milbrew, Incorporated is presently producing from cheese whey about two million gallons per year of fuel ethanol at its Juneau, Wisconsin facility and plans to expand the facility shortly in order to raise production levels to ten million gallons per year (the firm is also planning to construct a twenty million gallon per year plant, out of state, by 1986).^[8] Midwest Solvents Company, Atchison, Kansas, is producing about eight to ten thousand gallons per day of ethanol for fuel use.^[9] Additionally, the A. Smith Bowman distillery, Reston, Virginia, makers of Virginia Gentleman Bourbon, is expanding its plant capacity to make ethanol for fuel use. Current plans are for production of about 2,200 gallons per day.^[9,10]

Publicker Industries, Incorporated of Greenwich, Connecticut states that its existing facilities can produce about fifteen million gallons per year of fuel grade ethanol. A Publicker spokesman further stated that should the decision

to expand production occur now, production levels in one year could reach sixty million gallons per year (primarily from its Philadelphia plant).^[11] Also, the American Distilling Company, Pekin, Illinois, is currently considering an expansion of its facility in order to produce twenty to thirty million gallons per year of fuel grade ethanol.^[12]

There are several independent groups throughout the country attempting to raise capital to construct new ethanol fermentation plants specifically for fuel use. Examples include the following:

- Agri-Energy Corporation hopes to construct by 1981 a ten million gallon per year plant at Olivia, Minnesota using grain and molasses as feedstocks^[13]
- Cajun Sugar Cooperative and Louisiana Agri Fuels have reportedly reached a tentative agreement to build a thirty million gallon per year facility in Southern Louisiana by 1980^[14, 15],
- If negotiations proceed positively, the Holly Sugar Company, Tracy, California, may construct two plants, each producing twenty million gallons per year of ethanol from corn^[16],
- Two Texas groups are interested in constructing ethanol plants; the Rio Grande Sugar Growers, Incorporated (Santa Rosa) and Grain Producers, Incorporated (Hutto)^[17].

The Food and Agricultural Act of 1977 (Public Law 95-113) provides for Government loan guarantees of up to \$15 million for each of four pilot plants (a total of 27 proposals were submitted) designed to produce industrial hydrocarbons from agricultural and grain products. Two of the plants selected (as of this date, none of the selections have been finalized) involve ethanol. Midwest Solvents, Inc., Atchison, Kansas, was offered a \$15 million loan guarantee for a proposed pilot

bioconversion plant which will produce 10 million gallons of ethanol annually from sweet sorghum and possibly molasses. The plant, to be located in Santa Rosa, Texas, will produce both fuel grade ethanol and/or industrial grade ethanol (depending on market conditions)^[18,19]. The other ethanol project (also offered a \$15 million loan guarantee) was awarded to a joint team of U.S. Sugar and Savannah Foods. This project features an acid hydrolysis bagasse-to-alcohol plant and will involve some continued development work. The plant is tentatively planned for construction adjacent to a sugar mill in Clewiston, Florida. However, a one-year research and development program (Purdue University) is necessary to scale-up the technology for a commercial endeavor.^[18] Thus, this plant is at least three years away from production.

There have been numerous legislative proposals initiated by Congress (as of the preparation of this report) which if enacted could further stimulate the production of ethanol for the DOE fleet test program. The House Agriculture Committee approved the Sugar Stabilization Act which authorizes the Secretary of Agriculture to set up a revolving fund for Federal loan guarantees for research and development, and construction of pilot plants to convert sugarcane, sweet sorghum, and beets into fuel alcohol.^[20] Also, the Senate voted a two year extension (as part of S.892) of rural and small farm research and development programs which will provide \$500 million in Federally guaranteed loans which are to be used for constructing pilot plants for the production of Gasohol.^[21] Additionally, the House Agriculture Committee approved a bill (the National Alcohol Fuel and Farm Commodity Production Act of 1979) which authorizes up to \$800 million in Federal loans and loan guarantees for fuel alcohol production from agricultural products/wastes. The bill would authorize the Department of Agriculture to sell crop surpluses and forest wastes to plants which have been constructed under the program. This bill also

offers \$200 million in direct loans of up to \$1 million each for plants of less than 1 million gallons per year, and offers \$800 million in loan guarantees for supporting up to 90% of the cost of larger plants.[22,23]

It is important to note that although the outlook for fermentation ethanol production appears to be very positive, there may be a strong demand from the general public for Gasohol type fuels. Thus, competition from the consumer Gasohol market may restrict the availability of 200^o proof ethanol for DOE vehicular fleet testing.

CONCLUSIONS

The quantity of alcohol required to supply all of the U.S. Department of Energy's vehicular fleet test fuel needs during the period fiscal year 1980 through 1982 could reach on the order of 1.5 and 1.6 million gallons per year of 200^o proof ethanol and fuel-grade methanol, respectively. During the time frame of fiscal year 1982 through 1987, vehicular fleet testing fuel needs could approach, or even exceed, 8 and 10 million gallons per year of ethanol and methanol, respectively.

In terms of supply, all of the ethanol fleet test fuel requirements can be satisfied by domestic fermentation ethanol from non-petroleum/non-natural gas resources. Initially, the major ethanol fermentation firms (e.g., Archer Daniels Midland Company, Georgia-Pacific Corporation, Midwest Solvents Company, and Publicker Industries, Inc.) are potentially capable of supplying the necessary quantity of ethanol. As the test project progresses and fleet size expands, the outlook for ethanol supply from the major firms as well as from other private sources, both existing and planned, is very promising. This supply outlook could be altered significantly if an expanding Gasohol market demands a major portion of the available ethanol production. In this regard, it is in the Federal Government's best interest to arrange for ethanol supply agreements as soon as possible so that fleet test volume requirements can be assured.

The supply situation for methanol from non-petroleum/non-natural gas resources is not very promising. It appears that methanol produced from coal or biomass will not be available before 1985 at the earliest, assuming that a decision to construct a sizeable plant is made immediately. As such, fuel grade methanol for use in the reliability fleet test project will most likely have to be obtained from the existing petroleum/natural gas-based methanol market. This market is currently operating at a level below maximum capacity and several older "mothballed" plants can be reactivated if the economic situation warrants. Furthermore, the industry is large enough (1.05 billion gallons in 1978) to absorb the potential DOE demand. [24,25]

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