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ASSESSMENT/REVIEW OF METHANOL TECHNOLOGY AND UTILIZATION AS A FUEL

**INTERIM REPORT
AFLRL No. 161**

By

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**U.S. Army Fuels and Lubricants Research Laboratory
Southwest Research Institute
San Antonio, Texas**

Under Contract to

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20. ABSTRACT (Continued)

of choice for direct utilization is not neat methanol, but a methanol fuel containing materials such as isopentane or gasoline (up to 10 vol%) to improve cold start, volatility, and other fuel properties. Modifications of existing equipment are generally needed for direct use of fuel grade methanol except in fuel cells. Use of methanol at low concentrations as an additive or gasoline extender presents fewer problems of system corrosion and elastomer compatibility. A program to demonstrate the potential for utilization of methanol (both direct and as an extender) in DOD equipment has been recommended. Under this program, the Army would evaluate the equipment performance in various climates, test the equipment reliability/durability, and resolve related support questions on the safe and efficient storage, distribution, and use of methanol fuel.

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FOREWORD

This report was prepared at the U.S. Army Fuels and Lubricants Research Laboratory (USAFRLRL) located at Southwest Research Institute, San Antonio, TX, under Contract No. DAAK70-82-C-0001 during the period October 1981 through September 1982. Work was funded by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, VA, with Mr. F.W. Schaekel (DRDME-GL) serving as contract monitor. Project technical monitor was Mr. M.E. LePera, MERADCOM-DRDME-GL.

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I. INTRODUCTION

Alternative fuels are being studied to enhance, replace, or extend the current supply of petroleum-based gasolines and diesel fuels for both mobile and stationary uses. Among the materials being considered are propane, hydrogen, and alcohols. Propane-powered cars will be available for sale to the general public in the fall of 1982. Current advantages of propane include a lower cost and a more plentiful supply than the alternatives with a significant surplus expected to occur by 1985.(1)*

Hydrogen-powered engines have the advantage of low (regulated) combustion emissions, but the disadvantages include the need for special (e.g., cryogenic) storage. The formation of hydrogen (on-board) from materials such as methanol, which may be stored at ambient temperatures in less bulky and lighter containers, may eventually lead to extensive use of hydrogen-powered engines. However, this method is still in the developmental stage.

Alcohols, in particular methanol and ethanol, are currently being studied for feasibility of use as neat fuels, fuel extenders and/or improvers. Public acceptance of gasohol (10 percent ethanol in gasoline) peaked during the petroleum fuel shortage. Ethyl alcohol has gained public acceptance as an additive to a greater extent than methanol even though there is expected to be a 1.2 billion gallon methanol surplus by 1985. The technology is present, however, to place alcohol-fueled engines into production in a relatively short time.(2) The advantages for doing this, particularly with methanol, are generally: (3, 4)

- increased fuel octane quality
- increased power (achieved through an increase in engine's compression ratio)
- reduced specific energy consumption
- extended lean misfire limit
- reduced NO_x emissions

*Underscored numbers in parentheses refer to the list of references at the end of this report.

Other factors, such as ease of storage, distribution and lower cost, appear to make methanol a most promising alternate future fuel.

The purpose of this report, therefore, is to review (in greater detail) methyl alcohol manufacture through end use as a fuel for mobility/stationary equipment and provide a preliminary assessment of methanol as a fuel for Army use. Finally, recommendations for research, development, testing, and evaluation programs to evaluate the utilization of methanol in extending military fuel supplies are provided.

II. HISTORY

In 1661, it was discovered that methanol could be produced by the destructive distillation of wood. By the 1860s, it had been synthesized in the laboratory from methane, and in the 20th century, it was synthesized from carbon monoxide and hydrogen.(5)

Alcohol as a motor fuel was first recommended in 1895 by Nicklaus Otto, who is credited with the development of the four-stroke cycle internal combustion engine. Post-World War I France used a 1:1 blend of alcohol and gasoline in government vehicles. During the Great Depression, American farmers were making their own alcohol to power farm equipment. Alcohols used during these periods were mainly ethanol and tert-butanol.(6)

Interest in methanol as a candidate alternative fuel has increased since the 1930's due to the development of viable methods for the synthesis of large quantities of methanol. Prior to that time, it was available chiefly as a byproduct of charcoal manufacture. During World War II in Europe, some vehicles were operated on the fumes from wood burners, the vapors of which contained some methanol. Until recently, the major use of methanol as a motor fuel has been in racing cars where increased power is desirable over engine economics.(7, 8, 9)

III. MANUFACTURE

A. Methanol

Approximately 15 percent of the Gross National Product depends on methanol in one way or another.(3) Many sources are available for its production. Litton Industries is proposing to build barges which could be moved to areas which have large excess supplies of natural gas (especially pipeline LNG) but which are difficult to transport to economically feasible markets. Equipment on board the barges would be capable of converting the gas efficiently to methanol which can be more easily shipped.(10) Methanol may also be produced through synfuel technology using oil shale, coal gasification, or coal liquefaction techniques. However, little data are available on methanol and gasoline derived from these raw materials.(11) For several years, beginning in 1926, the duPont Company produced methanol from coal and coke until the cost and availability of natural gas as a feedstock became more economically attractive. Attention was then redirected toward coal as a result of the unfavorable long-term economic outlook for natural gas.(5) However, between 1970 and the present, improved exploration techniques have enabled discoveries of more oil and natural gas lying deeper in the earth.(12)

Today, one of the cheapest and most abundant feedstocks for manufacture of methanol is North Dakota lignite, mainly because of its high energy conversion efficiency (about 45 percent). However, coal or lignite liquefaction and subsequent refining would still provide a motor fuel with higher efficiency and lower cost than neat methanol from coal. Municipal refuse can also serve as a feedstock, but at a cost higher than that of lignite. Most of the successful efforts for producing methanol have been to gasify coal, then combine the proper ratio of CO and H₂ present to form methanol.(5) Sources of methanol production and utilization have been extensively discussed elsewhere.(4, 13) Figure 1 indicates the generalized links between raw feedstocks, synthesis and utilization of methanol as a fuel.

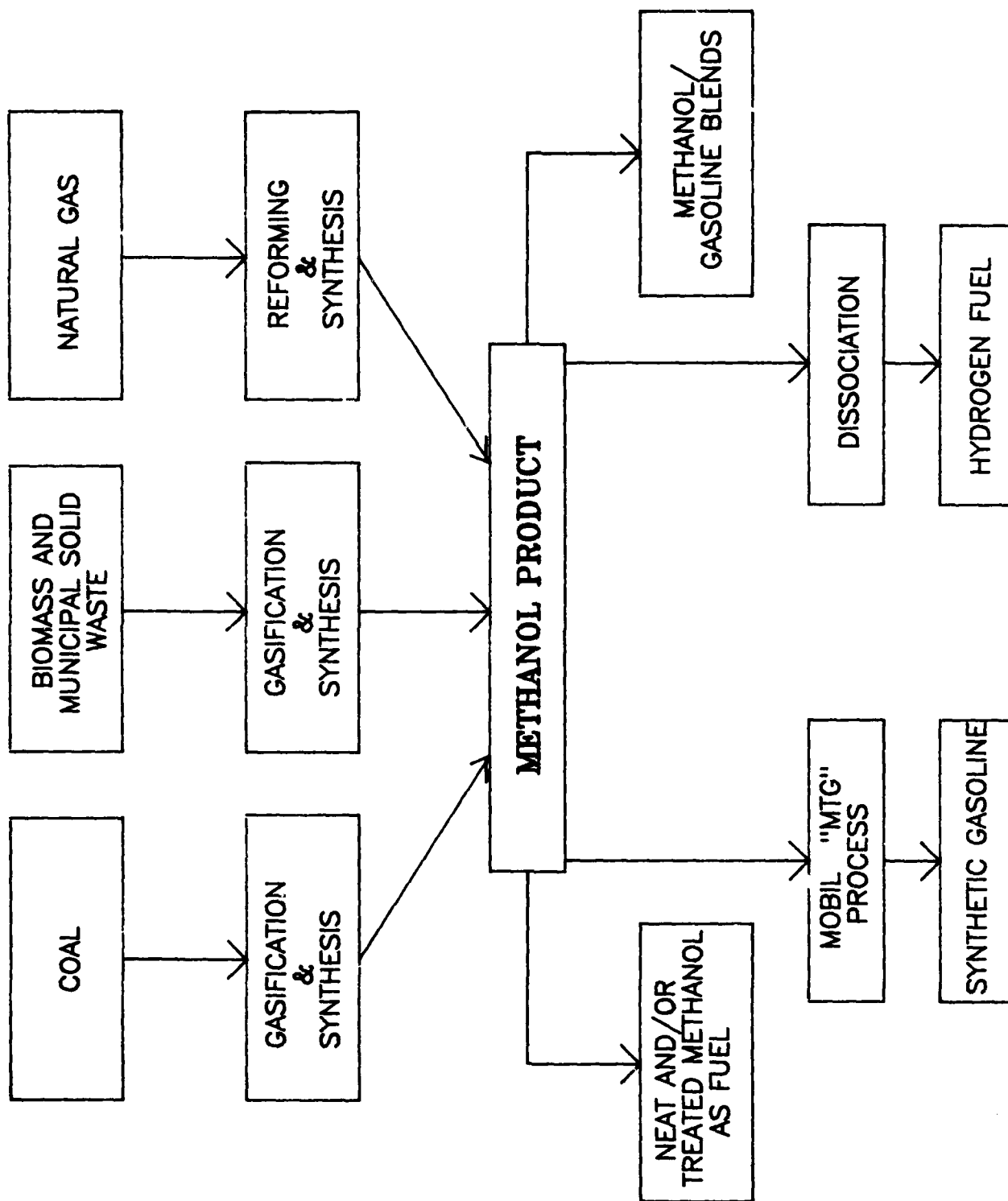


FIGURE 1. METHANOL FROM SOURCE TO UTILIZATION

B. Conversion of Methanol to Gasoline

Methanol from coal or natural gas can be converted to a high-quality gasoline usable without spark-ignition engine modification. The process is basically the employment of a selective zeolite molecular sieve catalyst which dehydrates methanol. The remaining methyl radicals combine to form a material similar in composition to high-octane gasoline. However, the chemistry of the process is actually quite complex.(12, 13)

The process is economically attractive. The conversion efficiency is essentially 100 percent (44 percent hydrocarbon, 56 percent water yield). Approximately 85 to 90 percent of the hydrocarbon products can be used as gasoline, with the remainder as fuel gas. The conversion is highly exothermic (about 1700 kJ/kg methanol input). In this process, 95 percent of energy of the input methanol is retained in the product hydrocarbon. The rest of the energy is left as heat of reaction, of which 2 to 3 percent is consumed as process energy, providing an overall energy efficiency of 92 to 93 percent (water contains no energy as a fuel).(12)

The gasoline product from the conversion process exceeds current requirements for unleaded gasoline in octane rating and impurities content. The high octane quality results from the fuel's content of naphthenes, aromatics, and highly branched paraffins and olefins. The gasoline contains no detectable impurities, such as sulfur, nitrogen, or oxygenates, since it was made from essentially pure methanol (aside from possible dissolved water). Its boiling range is comparable to that of premium gasoline.(14)

C. Methanol/Gasoline Blends

To successfully provide an acceptable blend of alcohol with gasoline to fuel current engine inventories certain problems, such as phase separation, corrosivity, stoichiometric air/fuel ratio and vapor pressure must be taken into consideration.(15) Several materials have been developed to overcome the above problems and aid in the blending process. These materials are Oxinol, Petrocoal Basic, Syncolene and Arconal. Oxinol was developed in

1978 by Suntech.(16) A waiver was obtained from EPA in June 1979 which would allow a 50/50 volume ratio of methanol/t-butyl alcohol to be used commercially in fuels at concentration up to 2% by weight fuel oxygen (or an addition of 5.5% by volume). A later revision allowed 3.5% by weight fuel oxygen (or an addition of 9.6% by volume) to be used.(17)

Petrocoal is a fuel developed by Anafuel Unlimited containing their ingredient "Petrocoal Basic". In October 1981 EPA granted a waiver allowing up to 12% methanol by volume and up to 6% C₄ alcohols in unleaded gasoline. However, the methanol/C₄ alcohol ratio must not exceed 6.5:1.(15) Arconol was developed by Atlantic Richfield. Its waiver was granted in February 1979 allowing up to 7% by volume of gasoline grade TBA to be added to unleaded gasoline. Sincolene (Synco 76 Fuel Corp.) was granted a waiver in May 1982 for 10% ethanol with a "proprietary additive" to be used in unleaded gasoline.(17)

The use of additives (including methanol) in unleaded gasoline must be approved by the EPA. However, this is not true for leaded gasoline since TEL content is the only additive that is regulated by EPA.(3)

IV. PROPERTIES AND USE

A. Properties

Methanol is a single compound with a definite molecular weight and a sharply defined boiling point. These factors contrast with petroleum cuts, which contain many different compounds and can only be described in terms of average molecular weight. Table 1 summarizes the physical and chemical properties of methanol and compares them to isooctane, a hydrocarbon representing many of the properties of gasoline. The operational performance of internal combustion and turbine engines is dependent upon the properties of methanol. Table 2 summarizes research and development and demonstration factors surrounding methanol use as a fuel.(18) Table 3 summarizes problems associated with methanol use under various conditions. The following sections provide more detailed discussions of the use of methanol as a fuel.

TABLE 1. PROPERTIES OF METHANOL AND ISOOCTANE

	<u>Methanol*</u>	<u>Isooctane</u>
Chemical Formula	CH_3OH	C_8H_{18}
Molecular Weight	32.04	114.23
Composition, wt%		
Carbon	37.5	84.2
Hydrogen	12.6	15.8
Oxygen	49.9	-
Specific Gravity 60/60°F	0.796	-
Density, g/cm^3 (lb/gal)	0.794 (6.63)	0.692 (5.77)
Boiling Temperature, °C (°F)	65 (149)	99.2 (211)
Flash Point, °C (°F)	11 (52)	-12 (10.4)
Autoignition Temperature, °C (°F)	464 (867)	415 (779)
Flammability Limits, vol%		
Lower	6.7	1.0
Higher	36.5	6.0
Lower Heating Value,		
kJ/kg (Btu/lb)	19,930 (8,570)	44,350 (19,080)
Latent Heat of Vaporization,		
kJ/kg (Btu/lb)	1,177 (506)	308 (132)
Vapor Pressure,		
kPa @ 38°C (psia @ 100°F)	31.9 (4.6)	11.7 (1.7)
Stoichiometric Air/Fuel Ratio	6.4	15.0
Water Solubility	Infinite	Insoluble

*Source: Reference No. 7.

**Source: Reference No. 19 (in part).

TABLE 2. RESEARCH, DEVELOPMENT AND DEMONSTRATION FACTORS
SURROUNDING USE OF METHANOL AS A FUEL

Area	Factors to Consider
Fuel Manufacture	Fuel Specifications: Processing and/or conversion techniques Fuels Composition
Fuel Distribution/ Retailing	Materials composition and water contamination: Accommodation/fuel transfer techniques Demonstration distribution systems Assess delivery equipment safety provisions Vapor capture nozzle, fire fighting equipment On site blending vs. production source blending Increased use of pumping systems More stations vs. larger vehicle fuel tanks Special labeling Spills Vapor emissions; refueling overflow OSHA requirements for safe fuel handling procedure
Mobility/Stationary Engine Use	Lubricant compatibility, cold start, vapor lock, fuel specifications. Availability of fuel supply for durability, reliability, fleet testing; driveability Compression ratio vs. octane, fuel preparation, fuel tanks, incorporation of new materials, vapor cannisters Manuals Special instruments and inspection requirements/procedures Combustion emissions
Boiler Burner Use	Availability of fuel supply for durability reliability. Fuel tanks, incorporation of new materials, fuel pumps, fuel flow systems, burner modifications Start-up/shut-down requirements, conversion vs. replacement Large scale/duration tests Operation manual Special instruments and inspection requirements/procedures

Source: Reference (18)

**TABLE 3. SUMMARY OF POTENTIAL OR ACTUAL PROBLEMS
ASSOCIATED WITH THE USE OF METHANOL AS A FUEL
IN SPARK-IGNITION, COMPRESSION- IGNITION, AND TURBINE ENGINE SYSTEMS**

<u>Area</u>	<u>Fuel Condition</u>	<u>Engine Type</u>	<u>Problem</u>
Utilization	Neat methanol, methanol/gasoline blends	Spark-ignition	Cold startability and driveability
Utilization	Methanol/gasoline blends	Spark-ignition	Cylinder and valve wear
Utilization	Neat methanol, methanol/gasoline blends	Spark-ignition	Vapor lock
Distribution and handling, storage, utilization	Methanol/gasoline blends	Spark-ignition	Water tolerance
Utilization (fuel delivery), distribution and handling, storage	Methanol/fuel blends and emul- sions, neat methanol	Spark-ignition, compression-ignition, turbine	Metals corrosion
Utilization (fuel delivery), distribution and handling	Methanol/fuel blends and emul- sions, neat methanol	Spark-ignition, compression-ignition, turbine	Elastomer incompatibility
Utilization	Neat methanol, methanol/fuel blends and emulsions	Spark-ignition, compression-ignition, turbine	Low heating value
Utilization, storage	Methanol/fuel blends and emulsions	Spark-ignition, compression-ignition, turbine	Oxidative stability
Utilization	Neat methanol	Compression-ignition	High autoignition temperature
Distribution and handling, storage, utilization	Neat methanol	Compression-ignition, turbine	Immiscibility with hydrocarbon fuel
Utilization	Neat methanol, methanol/fuel blends and emulsions	Compression-ignition, spark-ignition, turbine	Aldehyde emissions
Distribution and handling, storage, utilization	Neat methanol	Spark-ignition, compression-ignition, turbine	Toxicity, through ingestion and inhalation
Distribution and handling, utilization	Neat methanol	Spark-ignition, Compression-ignition, turbine	Flame invisibility
Distribution and handling	Neat methanol methanol/fuel blends and emulsions	Spark-ignition, Compression-ignition turbine	Detrimental impact on life ecosystems from spills
Distribution and handling, storage, utilization	Methanol/ fuel emulsions	Compression-ignition, turbine	Emulsion stability

Source: Reference (19).

1. Comparison to Gasoline

The compositional differences between methanol and gasoline account for differences in flash point, boiling temperature, heat of vaporization, heating value, air/fuel ratio, and water solubility. These differences are responsible for some of the problems in mixing or replacing gasoline with methanol.(7)

Methanol, with an octane number of 106, (compared to a 90-100 research octane number for a typical gasoline) increases the gasoline resistance to autoignition when blended with it. Methanol's high autoignition temperature of 385°C (compared to 220°C for unleaded gasoline) accounts for its high blending octane number.(20, 21)

2. Gasoline/Methanol Blends

When methanol is blended with gasoline, some properties characteristic of either component are moderated, such as octane quality, materials compatibility, thermal efficiency, and heating value. Others, such as volatility (boiling range and vapor pressure), are changed and do not appear characteristic of either. For example, the vapor pressure of neat methanol is lower than that of gasoline. Since it is a lower boiling alcohol, it forms an azeotrope with lower boiling hydrocarbons, and results in an initial boiling point lower than that of either component. This causes the vapor pressure of the methanol/gasoline blend to be higher than that of the base gasoline.(20)

a. Corrosion

As with neat methanol, methanol/gasoline blends can damage certain metals used in automotive fuel distribution systems. Among those components susceptible to corrosion are terne metal, zinc, aluminum, steel, low tin solders, and magnesium. Entrained water in blends may be responsible for corrosion to some extent.(7)

Methanol fuel can cause up to five times as much wear on unprotected surfaces (in the combustion chamber) as unleaded gasoline, although anhydrous ethyl alcohol and alcohol/ gasoline blends cause no increased wear. The creation of formic acid appears to be the dominant wear mechanism in combustion systems, the abatement of which requires answers to:(22)

1. What role surface effects play on formic acid formation;
2. the role of liquid boundary layers;
3. the kinetics of formic acid formation.

b. Water Tolerance

When enough water infiltrates a methanol/gasoline blend, especially as a result of distribution and handling, it mixes with the methanol component causing separation from the base gasoline. A blend's resistance to this phenomenon (maximum water solubility) is its water tolerance. Due to the hygroscopicity of methanol, methanol/gasoline blends can even undergo phase separation as a result of storage in vented tanks due to humidity and tank breathing.(7)

Water tolerance of an alcohol/gasoline blend depends upon four variables: blend temperature, gasoline composition, alcohol structure/purity (proof), and alcohol concentration. In general, water tolerance is directly related to increasing blend temperature, increasing aromatic content, increase of alcohol carbon number, and increase of alcohol concentration. It should be noted here that water tolerance is also related to boiling point of hydrocarbons within each of three classes; paraffins, olefins, and aromatics. Although water tolerance increases in the same order, the higher the boiling range of each class, the lower the blend's water tolerance. Also, for methanol/gasoline blends, below approximately 0.04 vol% water content, water tolerance is inversely related to methanol level. Above approximately 0.08 vol% water, the relationship is direct. Lastly, if a low-aromatic gasoline is added to a high-aromatic gasoline/alcohol blend, the resulting lowered methanol and aromatic concentration will result in lowered water tolerance.

c. Materials Compatibility

Methanol/gasoline blends (10-20 vol% methanol) can cause swelling of various elastomers.(23)

Although fluorosilicone, epichlorohydrin, and nitrile elastomers resist swelling in straight methyl alcohol, this is not true in fuel/alcohol mixtures. The volume change is great even at the 5 percent alcohol level. This also has a varying effect on tensile strength and hardness of the elastomers.(24)

Tests in New Zealand indicated saturation and swelling of cork, disintegration of microfilters, and "O" ring swelling.(24) Methanol is a good solvent, and thus can cause problems with synthetic and natural elastomers such as Viton®, neoprene, Buna-N, Teflon®, polyethylene, polypropylene, polyurethane, polyester-laminated fiberglass, polyvinyl chloride, acetal homopolymers, phenolic resins, epoxy coatings, leather, cork, paper, fiberboard, asbestos, coated cotton, and both sealants and bonding agents. These materials deteriorate faster in neat methanol than in methanol/gasoline blends.(7) Elastomers in compression-ignition engines are susceptible to deterioration from ethanol as well.(25)

B. Use

1. Spark Ignition Engines

When methanol is used as a fuel, a volatility-related problem known as cold startability can occur. Spark-ignition engines cannot usually start at temperatures below about 50°F on neat methanol without the use of extra heating or starting aids. A flammable air/fuel mixture must be present in the engine cylinders to achieve starting. Flammability limits and vapor pressures dictate that an air/methanol vapor mixture will be too lean to start an engine below 48°F.(7)

The volumetric heating value for methanol is approximately one-half that of gasoline. Thus, a vehicle would have to carry twice the amount of neat methanol as it would gasoline in order to achieve the same total heating value. It would also be necessary to meter fuel delivery at twice the rate for comparable engine output. An average size vehicle experiences a weight penalty, resulting in a fuel consumption increase of about 2 percent when using a gas tank twice as big. By adjusting compression ratios and making other modifications, a methanol-fueled car can actually have greater power output than a gasoline-fueled vehicle. Methanol-fueled cars can also take advantage of increased octane rating and fuel economy, since the thermal efficiency of methanol is about 10 percent higher than that of gasoline.(26)

The state of California modified a 1978 Ford Pinto engine to run on neat (fuel grade) methanol. Major engine changes to accommodate the fuel were increased compression ratio, shift in peak engine torque, and optimization of the fuel feed system. The overall performance of the car was excellent, but the terne plate from the fuel tank began dissolving and clogging the fuel tank filter screen, the internal screen in the electric pump, and the primary in-line fuel filter. This presents a minor driveability problem in which the fuel pump appeared to be failing. Cold starting required about 10-20 seconds, and fuel economy was good. The fuel mixture controller was adjusted for a rich mixture, which resulted in high hydrocarbon and carbon dioxide emissions. Nitrogen oxide emissions, however, were low.(27)

The State of California Energy Commission (CEC) established a test with three fleets of cars to determine the suitability of alcohol fuels and to aid in the development of necessary vehicle modifications. The prime contractor for the test was Ford Motor Company. During the test program, the following vehicle modifications were made:(28)

1. Compression ratio was changed from 8.8:1 to 11.4:1.
2. Carburetor recalibration (for higher flow).
3. Installation of corrosion-protected carburetors
(zinc parts were coated with nickel).

4. Installation of tin-plated fuel tanks.
5. Fuel pump diaphragm changed to an alcohol compatible elastomer.
6. Exhaust gas recirculation flow was increased to reduce NO_x emissions. The switch was relocated to the cylinder head so enough heat would be present to activate it.
7. Vacuum spark advance disconnected.

DuPont and Conoco, its newly acquired subsidiary, have begun fleet testing on both neat methanol fuel and methanol/gasoline blends. Neat (fuel grade) methanol cars are being driven by Conoco employees on normal business, and drivers are keeping records on fuel economy, driveability, and engine starting. A weather log is also being kept for its possible effects on performance.(29)

The state of North Carolina is currently experimenting with spark-ignition engines and a dual tank alcohol approach developed by Texas A&M University. The vehicles carry gasoline and alcohol each in separate tanks. The engines are started on gasoline, then alcohol is vaporized with exhaust heat and is fed to the carburetor (after gasoline is cut off) through a demand regulator.(29)

The city of Baltimore and Bank of America (B of A) are also experimenting with their own test fleets. Baltimore is using 90 percent MeOH-10 percent unleaded gasoline (30) while B of A used 2 to 18 percent alcohol blends and found 2%-4% alcohol to be acceptable and demonstrate overall cost savings.(3)

Experiments with gasohol (ethanol/gasoline) in a military L-141 engine showed economy to improve under heavy loading while it deteriorated under light and intermediate loading conditions. A nonemissions carburetor proved better for gasohol use with no effect on maximum power. Actual driving also showed no difference between fuels. A relatively short endurance test showed no change in wear products in the oil, although more frequent oil changes may be necessary. Cold starts of an LDT-465-1C engine (military-designed compression-ignition engine for multifuel use) showed that the fuel

had an inadequate cetane number to sustain normal operation. Therefore, the use of LDT-465 class of engines should be eliminated on alcohol-fueled equipment.(31) Similar results from methanol (rather than ethanol) in both the L-141 and LDT-465 would be anticipated.

2. Compression Ignition Engines

Methanol and other low carbon number alcohols in general have relatively high autoignition temperatures, and therefore do not satisfy cetane requirements of compression ignition engines. Numerous approaches have been explored to meet the cetane requirement. A common approach has been to fumigate the engine with methanol, and supply diesel fuel through the injection systems for only ignition and additional power. This method proved unsuccessful. The incoming mixture of methanol and air produced unburned methanol emissions and poor combustion efficiency, especially at low load conditions, since the lean mixtures necessary at low load conditions cannot sustain flame propagation across the combustion chamber. Another method is by use of distillate fuel pilot injection to initiate combustion and methanol injections for supplemental fuel and power increase. However, thermal efficiency is decreased as methanol content is increased. This approach can be improved if methanol and fuel are mixed prior to injection.(32)

Methanol has a very limited solubility in diesel fuel unless the aromatic content is abnormally high. Dry ethanol, however, is completely soluble in diesel fuel as long as the water content of the fuel is less than 0.5 percent. Attempts to use co-solvents (such as t-butanol in gasoline/alcohol blends) have not been undertaken to any great extent. The formation of stable emulsions rather than use of co-solvents to form alcohol/diesel fuel blends appears to be the trend of current research efforts.(33) This approach solves the miscibility problem, but creates others, such as poor long-term storage stability and compatibility with other diesel formulations. Surfactants which permit emulsion stability are quite expensive, may poison filter/water separators, and can produce unwanted exhaust emission species.(34)

The investigation into the applicability of methanol to compression ignition engines is being supported by the Departments of Energy and Transportation and the California Energy Commission. Field programs are mainly centered around municipal bus systems while laboratory work has been carried out on commercial engines by a number of contractors. The primary emphasis is on capability to retrofit vehicles for methanol use. Major methods of fuel introduction being investigated are fumigation, emulsification, co-injection and cetane-improved methanol. The former has the greatest probability for success, and the latter method the least. However, none of these processes has reached the commercial stage.

3. Turbine Engines

Information on research with alcohol fuels for aviation turbine engines is scarce. However, studies with alcohol-fueled stationary gas turbine engines used in power generation have revealed general problems similar to those for diesel and spark-ignition engines. These problems involve: lower Btu content, flash point, lubricity characteristics, corrosion, materials incompatibility, and methanol/methanol-combustion-product exhaust emissions.(35)

The military has studied the effects of methanol and ethanol in aviation systems a number of times and has consistently arrived at the following conclusions:

- Turbine engines can burn alcohols, but operating environments and total system consideration often dictate desired fuel characteristics.
- Alcohols offer more disadvantages than advantages (low-energy density, hygroscopicity, material incompatibility).
- Methanol is energy-inferior to petroleum turbine fuel by about 55 percent; thus extra fuel weight-iterations indicate that methanol would have a breakeven cost at 44 percent of that of petroleum (disregarding logistical costs).

Also, even if methanol became significantly cheaper than petroleum turbine

fuel, payload and/or range penalties would have to be accepted.(36)

Neglecting differences in energy content between alcohols and petroleum turbine fuel, the primary penalty is the added fuel weight (50 percent for ethanol, 100 percent for methanol).

Data for automotive spark ignition engines are fully applicable to their aircraft counterparts, thus beneficial work on aircraft engines is limited to designing, testing, and evaluating of models. One modification might be preheating of alcohol, since aircraft experience colder temperatures at higher elevations. The need for more heat also adds to safety concerns.(37)

Alcohols can be burned in turbine engines, provided they are modified for use. Turbine engines are insensitive to octane quality, whereas the higher octane number of alcohols is a definite advantage for spark ignition engines.(37) There is one outstanding advantage, however; the greater the oxygen availability to a jet turbine engine (or spark ignition engine), the better its efficiency. Oxygen is less plentiful at higher altitudes; therefore, engine performance is reduced. Methanol, a heavily oxygenated compound, provides a supply of oxygen and increases power at high altitudes.

4. Stationary/Nonvehicle Applications

In addition to its potential as an automotive fuel, methanol can serve as a safe, clean fuel for space heating and in power plants for nonpolluting generation of electricity. When used as a boiler fuel, methanol combustion results in zero particulate and sulfur compound emission, and very low or negligible emission of nitrogen oxide, carbon monoxide, unburned hydrocarbons, aldehydes or acids. In contrast to No. 5 fuel oil, methanol combustion also provides for higher efficiency in boiler applications by allowing higher heat-transfer rates.(21)

Fuel cells can be used to generate electricity for operation of relatively small equipment. Traditionally, hydrogen has been used to power fuel cells, but the direct employment of methanol has been demonstrated although it is

not simple to use.(21) The Army's Silent Light-weight Electric Energy Plant (SLEEP) family of electric power generators ranging from 1.5 kW to 5.0 kW is fueled by an aqueous solution of methyl alcohol. The procurement specification for methanol is the Federal Specification O-M-232, which has three grade classifications:

- Grade A - Synthetic, 99.85 percent by weight (solvent use).
- Grade AA - Synthetic, 99.85 percent by weight (hydrogen-carbon dioxide generation use).
- Grade C - Wood alcohol (denaturing grade).

Table 4 summarizes the requirements for methanol grades A and AA.

Grade C wood alcohol (denaturing grade) shall comply with Internal Revenue Service Regulations SDA1 of 26-CFR-212, *Formulas for Denatured Alcohols*.

Similarly, methanol can be dissociated through reforming to produce hydrogen and carbon monoxide and can be used as a power source for fuel cells. Between 1070°K and 1225°K, methanol will pyrolyze and dissociate, resulting in a gaseous mixture consisting of 50 percent dimethyl ether, 33.3 percent hydrogen, and 16.7 percent carbon monoxide. For this reason, methanol can possibly serve as an abundant source of hydrogen with a potential for use as an automotive fuel.(38) Storage of hydrogen on board a motor vehicle presents a high weight penalty due to the storage vessel itself. However, a potential solution to this problem is on-board hydrogen generation from storable liquid methanol.(39)

Two chemical processes can produce hydrogen from methanol--steam reforming and partial oxidation. In steam reforming, methanol reacts with water on a catalytic surface and produces gaseous hydrogen and carbon monoxide. The reaction is endothermic, requiring a heat supply (for which automobile exhaust heat might serve) as well as on-board water. In partial oxidation, methanol reacts with air either on a catalytic surface or a flame front and produces hydrogen and carbon monoxide. This reaction is exothermic and does not require a heat source. However, the hydrogen-rich product gas contains

TABLE 4. REQUIREMENT FOR GRADE A AND GRADE AA METHANOL

Characteristics	Grade A Requirement	Grade AA Requirement
Acetone and aldehydes, percent max	0.003	0.003
Acetone, percent max	--	0.001
Ethanol, percent max	--	0.001
Acidity (as Acetic Acid) percent max	0.003	0.003
Alkalinity, percent max as NH_3	0.003	0.003
Appearance	Clear and colorless	Clear and colorless
Carbonizable substances	No discoloration	No discoloration
Color	Not darker than Color Standard No. 5 of ASTM platinum-cobalt scale	Not darker than Color Standard No. 5 of ASTM platinum-cobalt scale
Distillation range	Not more than 1°C and shall include $64.6^\circ\text{C} \pm .10^\circ\text{C}$ at 760 mm	Not more than 1°C and shall include $64.6^\circ\text{C} \pm .10^\circ\text{C}$ at 760 mm
Hydrocarbons	No cloudiness or opalescence	No cloudiness or opalescence
Specific gravity, max	0.7928 at $20^\circ/20^\circ\text{C}$	0.7928 at $20^\circ/20^\circ\text{C}$
Percent methanol by weight, min	99.85	99.85
Nonvolatile content, percent max	0.0010	0.0010
Odor	Characteristic, nonresidual	Characteristic, nonresidual
Permanganate test	No discharge of color in 30 minutes	No discharge of color in 30 minutes
Water, percent max	0.15	0.10

Source: Federal Specification O-M-232a

some nitrogen (which is in low enough concentration to have no effect on the hydrogen end use), whereas no nitrogen is produced in the steam-reformed gas. (38, 39)

Space heaters, water heaters, refrigeration units, and virtually any appliance which can be operated by gasoline or kerosene combustion in a steady-state mode can potentially be methanol-fueled with little or no modifications. Aside from problems associated with use of methanol as a mobility fuel (e.g. elastomer deterioration, metals corrosion, and heat of vaporization), an obvious disadvantage in its use as a stationary, nonvehicular fuel is its comparatively low heat of combustion--approximately one-half that of hydrocarbon fuels.(40)

C. Combustion/Emissions

1. Combustion

Incomplete methanol combustion products such as formaldehyde and formic acid, as well as other intermediate oxidation products, can attack metal and cause corrosion and metal particle removal around piston rings. Methanol also has a high heat of vaporization which can cause incompletely vaporized methanol to accumulate on cylinder walls and dissolve lubricant, leading to wear. Also, at lower engine temperatures, methanol combustion products interfere with normal corrosion protection.(41) This indicates that normal additives or synthetic lubricants can be ineffective. The combustion products which react with metal and produce iron formate at low engine temperatures decompose at high temperatures before iron formate can form. Thus, they do not contribute significantly to wear at the higher operating temperatures.(22) While this work has been done with commercial engines, there is no reason to believe similar military engines would be immune to corrosion problems associated with methanol.

2. Emissions

Methanol generally exhibits the following exhaust characteristics:

- NOx emissions are one-half that of gasoline.
- CO emissions in the lean region are similar to that of gasoline, but lower in the rich region.
- Unburned hydrocarbons are lower for methanol than for gasoline.
- Aldehyde emissions are higher for methanol than for gasoline.(42)

Aldehydes formed as combustion products can photochemically decompose to produce visible smog. Carburetor adjustment and use of catalytic converters can reduce aldehyde emissions to some degree.(7) Neat methanol combustion emissions are less photochemically reactive than gasoline. However, methanol gasoline blends do not appear to reduce the photochemically active species when compared to gasoline itself.(43)

3. Stability

Oxidative degradation of fuel can cause clogging of fuel lines, carburetor orifices, and intake manifolds. Gum deposits on valves can cause failure due to sticking. Gum is the final product of oxidation and polymerization reactions which principally involve olefinic constituents of gasolines. Storage testing has shown that, pure methanol has good storage stability, however methanol/gasoline blends exhibit poorer storage stability than their respective base components.(7)

V. SAFETY AND THE ENVIRONMENT

Methanol is a toxic substance that can enter the body through inhalation, ingestion, or absorption through the skin. Methanol has a low odor density, so persons could be exposed to hazardous levels without realizing it, such as from spills on clothing or use in poorly ventilated areas. Although there is great uncertainty as to the lower limit of human detection of

methanol odor, values from 100 to 2000 ppm have been reported. Use of odorants which coevaporate with methanol are possible solutions to the detection problem.(7, 44)

Ingestion (such as from siphoning by mouth) is a problem unless adequate odorous, unpalatable, or odd-appearing denaturants are used. Even ingestion of a small quantity (30-100 ml) of methanol can result in blindness or death.(7, 43, 44)

Neat methanol fuel would present a hazard in that it burns with a nearly invisible flame; however, with 5-10 vol% gasoline or 2 vol% toluene added, the blend will burn with a visible flame.(7, 26)

Although flammability limits, flash points, and ignition temperatures are known for both gasoline and methanol, little investigation of proposed blends have been undertaken. Methanol's flammability limit can be modified with the addition of pentane to result in a vapor/liquid ratio too vapor-rich to burn at ambient temperatures. Flammability limits can be modified at individual temperature regions only, not through a broad temperature range. Methanol does have a flash point higher than that of gasoline, presenting slightly less danger in the event of spills at sufficiently low temperatures.(26)

Methanol spills and leaks in transportation facilities can have impact upon terrestrial and aquatic ecosystems. Methanol as a toxic substance will highly affect microflora and microfauna in close proximity to major spills, however, small marine and estuarine organisms exposed to less than 1 percent methanol will hardly be affected. Even microorganisms upon which methanol is spilled show a 90 percent recovery within a few weeks, in contrast to a gasoline spill, from which they may take several months to recover. Methanol is biologically degradable by a nonpathogenic bacterium and, coupled with the high volatility of methanol, land or marine spills are removed naturally. Unfortunately existing techniques for removal of gasoline or oil spills do not apply to alcohol spills due to the alcohols miscibility with water.(43, 26)

The widespread public use of methanol will present chronic, low-level methanol leakage. Although small quantities of methanol are naturally present in marine environments, limited data are available to describe the short- or long-range impact on terrestrial or aquatic ecosystems.(26)

VI. STATE-OF-THE-ART: PRODUCTION AND TECHNOLOGY

As of 1979, the United States methanol production was roughly 85,000 barrels per calendar day, with the largest plant producing 18,000 barrels per calendar day. Most of the methanol supply has been and still is produced from natural gas and consumed as an industrial chemical.(3)

Several alternatives exist for the production of methanol. Solid municipal waste is not practical, due to the amount of feedstock needed, and therefore product methanol could only be used as a gasoline supplement or extender. This technology, however, is still in its infancy. Other potential feedstocks are marine products and wastes. Total energy in these feedstocks is equivalent to 2 billion barrels of crude oil, or about 30 percent of the United States' annual consumption. Only small fractions are being collected and not all is recoverable.(3)

Production of methanol from coal has been potentially available for years and is gaining in popularity due to better economic conditions. In producing methanol from lignite (brown coal), the lignite is pulverized, dried, and fed to a gasifier, along with steam and oxygen. Clean product gases (H_2 , CO , CO_2) are adjusted to the proper ratios, and from these, methanol is synthesized, using a low-pressure process employing a $Cu/Zn/Cr$ catalyst.(3, 45)

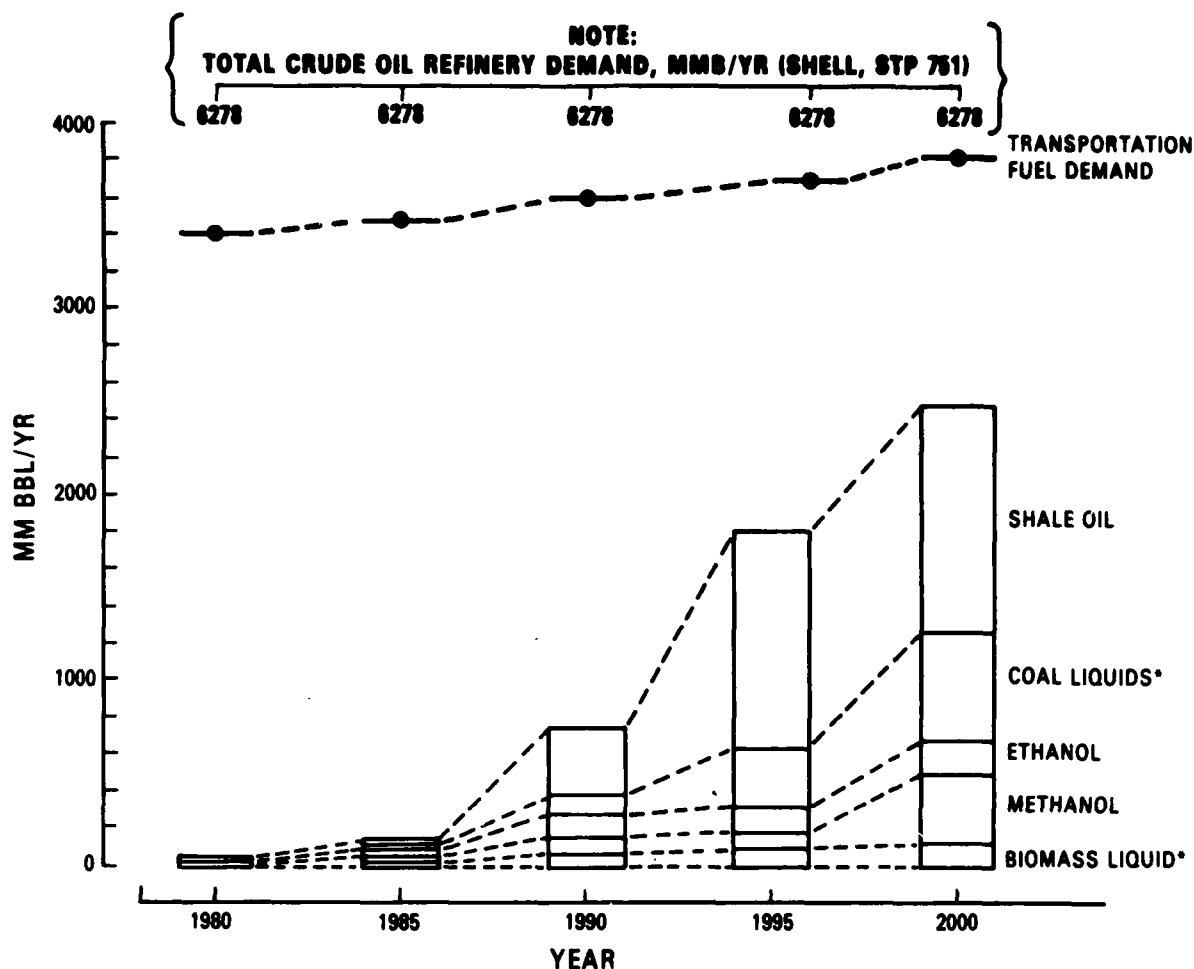
Methanol from cellulosic (biomass) feedstock has two advantages over methanol from coal; feedstocks are renewable, and conversion has less serious environmental consequences. The disadvantage is that methanol from biomass is currently more expensive than methanol from coal, considering feedstock production and transportation cost, but as petroleum prices rise, the source will become more attractive.(45)

Union Carbide and Battelle Columbus have had some success with wood gasification. Union Carbide uses a vertical shaft furnace in which wood chips are partially oxidized to produce carbon monoxide and hydrogen. Chips burned in the lower part of the furnace provide heat to partially gasify chips in the upper part. The Battelle process employs a hot sand fluid-bed gasifier. Sand is heated in a combustor that burns wood char and eliminates the need for oxygen. Both processes, however, consume large amounts of feedstock per unit of methanol produced.(3)

Production of methanol as a feedstock for synthetic gasoline via Mobil "MTG" Process is receiving considerable attention. With this technology, considerable quantities of gasoline could be produced in the near term with no more distribution and use problems than currently associated with gasoline handling. This is an advantage over methanol fuel use which would dictate a major overhaul of handling practices. However, the synthesis process results in a fuel which sacrifices energy and neat methanol's low-emission characteristics, so trade-offs will have to be weighed.(45)

A number of commercial scale demonstration level coal-gasification facilities are in the United States. Although they are not specifically designed to produce methanol, they do produce a quality of gas usable for methanol synthesis. Their combined capacity could produce enough methanol for fleet testing, about 150 tons per day.(46)

During a recent study at the Army Fuels and Lubricants Research Laboratory (AFLRL) looking to alternate/synthetic future fuels availability, Figure 2 was developed to relate current and future maximum potential production growth of these fuels as related to the projected transportation fuel demand through the year 2000. Methanol and ethanol (including that derived from coal and biomass) are potentially the only new fuels which will be readily available as transportation fuels in the near term (through 1986) and the mid-term (1986-1996). Shale and coal liquids (nonalcohols) not used to directly supply the total crude oil refinery demand or direct use to make heat or electricity, are projected to be highly refined to make common fuel types such as diesel, gasoline, and jet fuels. Note in Figure 2 that in



*BIOMASS LIQUIDS INCLUDE ALCOHOLS.
COAL LIQUIDS INCLUDE SOME ALCOHOL FROM COAL.

FIGURE 2. TRANSPORTATION FUEL DEMAND AND ALTERNATE FUEL SOURCE
POTENTIAL PRODUCTION PROJECTIONS
(MAXIMUM SCENARIO)

terms of transportation fuel demand, methanol potentially contributes very little to the total demand through 1995.

VII. COMMERCIALIZATION

Commercialization of methanol on a significant scale would involve major new investments, resulting in high retail cost. Transportation costs would be high compared to petroleum commodities because of distance between plants and major markets as well as high volume of transported methanol to compensate for the methanol/petroleum energy difference.(3)

VIII. ECONOMICS AND PRODUCTION COSTS

No domestic plants to produce methanol commercially from coal are in operation in the U.S. at present, but, based on present technology and abundance of coal deposits, methanol could be produced for about one-half the price of gasoline and equal to the price of gasoline on a constant energy basis. Automobiles properly designed for methanol fuel use are expected to achieve about 20 percent better fuel economy based on these facts. (45)

Cost estimations and projections in "real" dollars for production of methanol from coal can be made on the basis of assumed plant efficiencies, coal characteristics, plant life, year of construction, interest rates, etc., once these factors are used as data from study of the industry. Capital investment, also in "real" dollars, can be scaled up by means of the equation:

$$\text{Cost of Plant B} = \left[\text{Cost of Plant A} \right] \cdot \left[\frac{\text{Size of Plant B}}{\text{Size of Plant A}} \right]^x$$

where x ranges from 0.6 to 0.7.

With this equation, the total capital investment for any size methanol plant can be estimated, provided the tons of feed coal per day are known. Operating costs fall into three categories; those proportional to plant size, those that are some percentage of plant investment, and those that show economies of scale different from capital costs. (47)

A lignite plant designed to produce 120,000 barrels of methanol per day would require a total investment of \$1.8 billion (\$15,000 per daily barrel of methanol) on the basis of 3 pounds of lignite would be required to produce 1 pound of methanol. A plant using solid municipal waste as feedstock would produce 12,000 barrels of methanol per day and would require a \$338 million investment (\$28,000 per daily barrel of methanol). This plant would require 5 pounds of waste to produce 1 pound of methanol. These methods contrast with a 200,000 barrel per day petroleum refinery which would require an investment of \$3-4 thousand per daily barrel of crude run. Annual

capitalized charges for producing methanol from the two feedstocks take about 20 percent of the investment. A credit of \$27 is allowed per ton of sulfur recovered from lignite, and it is possible that a waste plant would be paid \$5 per ton for waste it accepts.(3)

IX. DISTRIBUTION AND HANDLING

To date, three methods of blending and distributing methanol/gasoline blends are possible; refinery blending, storage depot blending, and service station blending. The closer the blending operation to the refinery, the more economical, but the chances of its quality being poor when it reaches the consumer are greatly increased. The advantages and disadvantages of each type of blending operation are as follows:(48)

A. Refinery Blending

Advantages

1. Fuel meets specifications before leaving refinery.
2. Blending is carried out under optimum conditions.
3. Only a few supply points for the methanol component are needed.

Disadvantages

1. Risk of water contamination before blend is purchased by consumer.
2. Risk of corrosion due to ingress of water.

B. Storage Depot Blending

Advantages

1. Reduced chance of water contamination by end-use.
2. Regional distribution of methanol/gasoline blends is possible in countries with few refineries and/or large climate variations due to area.

Disadvantages

1. Higher distribution costs than with refinery blending.
2. Poor blending control.
3. Personnel training required.
4. More stringent quality control measures required.

5. Numerous supply points for methanol involved.
6. Increased risks of methanol spills.

C. Service Station Blending

Advantages

1. Minimal risk of phase separation.
2. Greater flexibility if future automobiles become equipped for methanol/gasoline use as ratios of components change.

Disadvantages

1. High distribution costs.
2. High capital investment required.
3. Good blending control, but no quality assurance confirmation.
4. High risk of methanol spills.

X. LEGAL AND REGULATORY INFLUENCES

Title I of the Energy Security Act (Public Law 96-294; June 30, 1980) establishes the Synthetic Fuels Corporation, while Title II creates the Office of Alcohol Fuels. The Synthetic Fuels Corporation is authorized to issue financial assistance to synthetic fuels projects in forms of loan guarantees, purchase agreements, and direct loans. Coal, shale, and tar sands are within the Corporation's purview, and since methanol can be derived from coal, it is within the Corporation's commercialization responsibilities.(45)

The United States Government has provided funding and laws for ethanol production and its use as an automotive fuel extender. "Gasohol," a 10 percent blend of ethanol in regular unleaded gasoline, has been in use since 1978; however, to date there is no significant demand for fuel methanol, and as a result, no fuel methanol is being produced. Supply as well as demand has to be influenced by decisions. The successful use of "gasohol" and the lower cost of methanol compared with ethanol could prove influential for implementing methanol-for-fuel legislation. Some commercial activities are in operation to demonstrate or assess the viability of methanol production from coal to supply electric power generation.(49)

The Department of Energy thus far has not established goals for methanol production regardless of its potential to replace gasoline, although efforts have been made to develop such a plan as part of an overall program.(45) The overall objective of this program is to provide information considered essential for the introduction of alcohol fuels as one means for supplementing and eventually supplanting petroleum-derived fuels.(18)

XI. NATIONAL ALCOHOL FUELS COMMISSION

The National Alcohol Fuels Commission was established by Congress in 1978 to investigate the potential of alcohol fuels. The Commission has received requests from potential investors in production facilities for descriptions of programs of federal agencies involved in alcohol fuels. Requests are for programs providing financial assistance for investors or Federal requirements to be met before entering the markets. Table 5 summarizes descriptions of some programs offered by individual Federal offices.(50)

TABLE 5. SOME FEDERAL PROGRAMS FOR FUNDING OF ALCOHOL FUELS TECHNOLOGY AND MARKETING

<u>Federal Agency</u>	Department of Energy
<u>Provision</u>	Commercial-size plants
<u>Types of Funding</u>	Direct loans, cooperative agreements, loan guarantees, purchase commitments, and price guarantees.
<u>Funding Limits</u>	\$100 million for feasibility studies (not to exceed \$4 million each). \$100 million for cooperative agreements (not to exceed \$25 million each). Applicant must provide 50% of project costs.
<u>Eligibility Criteria</u>	Alternative fuel must be derived from coal/lignite, shale, tar sands, unconventional gases, peat, biomass, solid wastes (industrial and municipal), or other mineral or organic mater-

TABLE 5. SOME FEDERAL PROGRAMS FOR FUNDING OF ALCOHOL
FUELS TECHNOLOGY AND MARKETING (continued)

	ials. Projects must produce at least one million gallons per year. Energy source for the project must be domestic.
<u>Federal Agency</u>	Economic Development Administration/Department of Commerce
<u>Provision</u>	Small-scale profit and nonprofit projects
<u>Types of Funding</u>	Direct loans and loan guarantees to the private sector. Direct grants to public and nonprofit organizations. No R&D funding.
<u>Funding Limits</u>	\$10 million for FY79-80 for small-scale alcohol fuel plants. Direct loans limited to 15% of project cost and for full amount of operating capital. Loan guarantees limited to 90% of project cost or 90% of operating capital.
<u>Eligibility Criteria</u>	Project site must be in an EDA "designated re-development area;" plant designed to produce less than 2 million gallons per year. Plants that use oil and gas for fuel are discouraged. Number of permanent new jobs to be created is a key consideration. No R&D funding provided.
<u>Federal Agency</u>	Farmers Home Administration/USDA
<u>Provision</u>	Large- and medium-scale plants
<u>Types of Funding</u>	Loan guarantees.
<u>Funding Limits</u>	\$1.5 billion for FY 1980, but no application may exceed \$50 million. Applications for \$1 million or less can be reviewed at the state level, those for over \$1 million to be considered by FHA executive committee.
<u>Eligibility Criteria</u>	Business and industrial loans can be guaranteed in each of the 50 states, Puerto Rico, and the Virgin Islands, but are restricted to operations in open country, rural communities, and in towns of 25,000 or less.

TABLE 5. SOME FEDERAL PROGRAMS FOR FUNDING OF ALCOHOL
FUELS TECHNOLOGY AND MARKETING (continued)

<u>Federal Agency</u>	Small Business Administration
<u>Provision</u>	Small businesses which are developing, manufacturing, selling, installing, or servicing specific energy conservation measures.
<u>Types of Funding</u>	Direct loans and loan guarantees.
<u>Funding Limits</u>	\$75 million available. FY 1979: \$12.5 million in direct loans (at 8-1/4% interest), and \$30 million in loan guarantees. FY 1980: \$15 million for direct loans (at higher interest rate) and \$35 million in loan guarantees. Direct loans cannot exceed \$350,000. Loan guarantees cannot exceed \$500,000 or 90% of total loan. Maximum of 15 years repayment period.
<u>Eligibility Criteria</u>	Loans made only if loans from nonfederal sources are not available. Applicant must pledge collateral. Energy loans are not available to a business concern for installing or undertaking energy conservation measures in its own plant or office. Energy loan funds cannot be used for R&D except under special circumstances.
<u>Federal Agency</u>	Science and Education Administration/USDA
<u>Provision</u>	Universities for research on the production of alcohols and industrial hydrocarbons from agricultural and forest products.
<u>Types of Funding</u>	Direct project grants.
<u>Funding Limits</u>	Maximum of \$100,000 per grant in FY 1980.
<u>Eligibility Criteria</u>	Must be a college or university.
<u>Federal Agency</u>	Farm and Family Programs/USDA
<u>Provision</u>	Farmers and farm cooperatives to improve farm technology, administration and productivity for the development of alternative energy sources.
<u>Types of Funding</u>	Direct loans and loan guarantees.

TABLE 5. SOME FEDERAL PROGRAMS FOR FUNDING OF ALCOHOL
FUELS TECHNOLOGY AND MARKETING (continued)

<u>Funding Limits</u>	Farm ownership loans are scheduled according to borrower's ability to pay (maximum term is 40 years). Farm operating loans are tailored to borrower's needs with interest rates scheduled in a case-by-case manner.
<u>Eligibility Criteria</u>	Borrowers must be farmers or farm cooperatives, possess legal capacity for legal obligations of the loan, have ability to repay, be unable to obtain credit elsewhere, and rely on farm income to maintain adequate standard of living.
<u>Federal Agency</u>	Biomass Energy Systems Program/DOE
<u>Provision</u>	Universities and small businesses for biomass-to-alcohol R&D.
<u>Types of Funding</u>	Ongoing contract renewal authorized by Solar Energy Research Institute under agreement with DOE.
<u>Funding Limits</u>	FY 1980: ethanol \$11.5 million, methanol \$5.6 million; FY 1981: (requested) ethanol \$14.6 million, methanol \$4.7 million. No specific limits for each award.
<u>Eligibility Criteria</u>	Applicants must contemplate medium range R&D projects in the advanced alcohol conversion process area.
<u>Federal Agency</u>	Small-Scale Technology/DOE
<u>Provision</u>	Small businesses, state and local governments, nonprofit organizations, and Indian tribes for research, concept development, and demonstration of small-scale renewable energy sources.
<u>Types of Funding</u>	Direct grants.
<u>Funding Limits</u>	Up to \$50,000 per project of up to two years' duration. \$8 million was appropriated for this program in FY 1980.

TABLE 5. SOME FEDERAL PROGRAMS FOR FUNDING OF ALCOHOL
FUELS TECHNOLOGY AND MARKETING (continued)

<u>Eligibility Criteria</u>	Program generally considers unique technologies (e.g., ethanol from potatoes but not from corn).
<u>Federal Agency</u>	Urban Waste Programs/DOE
<u>Provision</u>	Small institutions, individuals, Indian tribes, and state and local governments for research and development for converting municipal waste to alcohol.
<u>Types of Funding</u>	Research grants and contracts for feasibility studies, cooperative agreements, price guarantees, and construction loan guarantees.
<u>Funding Limits</u>	Total funds available: \$100 million for feasibility studies, \$100 million for cooperative agreements, \$1.5 billion for price guarantees, and \$1.5 billion for construction loan guarantees.
<u>Eligibility Criteria</u>	Applicant's proposed plant must be large enough to be able to generate the revenue needed to meet both operating costs and construction loan repayment.

XII. INTERNATIONAL ALCOHOL FUELS ACTIVITIES

Numerous nations have been studying methanol technology and its potential as a motor vehicle fuel. The following is a summary of major international participants.

Canada

Canada will be economically hurt as petroleum prices rise or in the event of a cutoff of petroleum. To circumvent potential problems, methanol is a cost-competitive and an environmentally attractive near-term option. Long-term, renewable forest biomass appears to be the

most feasible for large-scale methanol production. Although Canada's coal resources are plentiful, their development for fuel production would meet environmental and political constraints.(51)

The purpose of a methanol fuel market is to displace petroleum-derived gasoline and diesel fuel on a large scale. This option provides utilization of end-use technologies readily available within time periods needed to build up large-scale methanol supplies. No methanol fuel market currently exists in Canada, and no private or government entity has taken a lead in its development. Methanol fuel development will present large investment requirements under which private investors risk poor profit margins. Development will be affected by associated long-term institutional development targets.(51)

Sweden

Many methanol plants in Sweden are out of date, and total effective production capacity for the nation is about 11 million tonnes/year. Sweden imports about 0.13 million tonnes/year, mostly from the Netherlands. Most imported methanol is obtained on long-term contract, with the remainder purchased on the spot market. At present, there is no market price for methanol in the large quantities required by a typical fuel contract (e.g., 200,000 tonnes/year for 10 years). However, in terms of energy cost, the large-scale import price would be about the same as that for petroleum, resulting in no added cost to Sweden.(52)

An alternative to importation of methanol directly is the importation of coal and residuals from "North Sea oil" and other nations. The major obstacle to this activity is the lack of knowledge and experience on the part of Sweden with coal gasification on a commercial scale. However, with considerable investment, it can be assumed that current technical development will provide an adequate basis for a large-scale project in a few years.(52)

Several of Sweden's own raw materials could become potential feedstock for methanol manufacture; peat, wood residues, straw, controlled forestry, and shale. However, these materials are somewhat inadequate as resources mainly because of many applications where they can replace oil. Only large-scale forest cultivation might alleviate the problem.(52)

Brazil

Production of methanol is limited, but several projects are underway to produce it from eucalyptus trees. Ongoing investigations are concerned with the behavior of gasoline/ethanol/methanol mixtures. Thus far, 6 vol% methanol in gasoline provides satisfactory spark-ignition engine operation but phase separation is still a problem.(53)

New Zealand

Vehicle fleet tests utilizing "M-15", a blend of 15 vol% methanol and 85 vol% gasoline showed that test vehicles have experienced no problems other than some elastomer incompatibility and a few volatility-related problems. Implementation of a large-scale distribution trial to several areas is planned, although a study of the present distribution system indicates that should an optimum blend be introduced nationally, storage and in-line blending of methanol and gasoline at ocean terminals would be acceptable.(8) Further testing of blends up to 25 vol% methanol showed no additional problems.(54)

Germany

Based on the current state-of-the-art of methanol fuel technology and economics and vehicle fleet tests, the following are possible applications of methanol as fuel:

- Methanol/gasoline blends of up to 20 vol% methanol require only minor engine and vehicle modification.
- Dual fuel operation is achievable with up to 30 vol% methanol but has the disadvantage of two fuel tanks.

- Pure methanol or 90 percent methanol with higher alcohols to avoid preignition would require major engine modification.
- Operation of diesel engines on methanol or methanol/diesel blends would require engine modifications and use of ignition-improving additives.(55) Methanol use as an octane improver is estimated to be present in 30% of the gasoline in Germany.

Japan

Japanese researchers have studied the use of dissociated methanol by catalytic reforming in spark-ignition engines. Thermal efficiency has been shown to be high, and exhaust emissions clean, although these can be optimized by adjusting engine parameters, such as compression ratio and fuel/air ratio.(56) Formaldehyde emission studies on spark-ignition engines utilizing methanol fuel indicate that formaldehyde formation from unburned methanol begins in the cylinders or exhaust port. Formaldehyde accumulation generally occurs at temperatures ranging from 400°-500°C in the exhaust tube.(57)

XIII. ASSESSMENT OF METHANOL CONVERSION FEASIBILITY

A program aimed at assessing the feasibility of converting commercial vehicle fleets to use methanol as a fuel was undertaken in early 1982 by the U.S. Government Accounting Office (GAO).(58) The results of this program indicate that:

1. Methanol-powered vehicles emit from 6 to 69 percent less NO_x than gasoline-powered vehicles.
2. CH_x and CO emissions yield mixed results; however, the difference with respect to gasoline-powered engines is minimal. Methanol-fueled vehicles could potentially have lower CO emissions if the fuel-air mixture were leaned out.

3. Emission of photo chemically reactive "chemical species" is less using methanol.
4. Converting and operating a vehicle on methanol could cost from \$1288 to \$6657, assuming a 3-year, 100,000 mile vehicle lifetime and a \$1500 mechanical conversion fee.
5. Future fluctuations in methanol/gasoline prices at the pump would offset overall operating cost estimations.
6. To use methanol fuel solely as an offset to increased NO_x emissions from a stationary source is not cost-effective at this time.

XIV. CONCLUSIONS AND RECOMMENDATIONS

This report has provided a review of methanol technology and a preliminary assessment of its potential for utilization as a mobility/stationary equipment fuel. In the public sector, methanol is already being used as a fuel in special spark ignition engines and as a gasoline additive/extender to a limited extent. Generally, the methanol fuel is not neat methanol but contains materials such as isopentane or gasoline, at concentrations around 10 percent, to alter its cold start, vapor pressure, and other properties. An aqueous solution of methanol is used as a fuel in the Army's family of electric power generators (fuel cells). A preliminary assessment does indicate a high degree of technical feasibility for both increased methanol production as well as broad use of methanol as a fuel principally in burners, turbines, and spark ignition engines. Since examples were found of direct utilization of methanol as a replacement for gasoline but not diesel fuels, it is recommended that a program should be considered which demonstrates the potential for utilization of methanol (both direct and as an extender) in DOD ground equipment. Under this program, the Army would evaluate the equipment performance in various climates, test equipment reliability/durability, and resolve related support questions on the safe

and efficient storage, distribution, and use of methanol fuel. This methanol utilization program would generally encompass testing and evaluations in addition to a methodology for and assessment of ground tactical and administrative equipment inventories for both direct utilization (with and without minor/major system changes) and indirect utilization by blending with gasoline. One possibility for initial consideration would be to explore the potential for allowing up to 3 percent methanol in administrative-type gasolines. Comparable commercial fuels are marketed to a limited extent in the U.S. and to a greater extent in other nations such as Germany. For additional references, an annotated bibliography has been provided in Appendix A.

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57. Likos, W.E., Yost, D.M., "Impact of Gasohol on the L-141 and LDT-465-1C Engines," Interim Report AFLRL No. 148, December 1981.

Gasohol was analyzed in the L-141 and LDT-465-1C engines in order to determine its impact upon engine operability. Conclusion was that gasohol not be used in the LDT-465 family of engines.

58. McCracken, Dudley, "Hydrocarbon Combustion and Physical Properties," NTIS BRL-R-1496, AD 714674, September 1970.

A compendium of various data on a large variety of chemicals.

59. McLean, W.J., "Use of Dissociated Methanol to Improve Automotive Engine Efficiency," (letter to D.W. Naegeli), Research Program at College of Engineering, Cornell University, Ithaca, NY, May 1977.

Enclosure states proposed research to determine the feasibility of substantial improvement in SI engines with dissociated methanol.

60. Mengenhauser, J.V., "Fleet Tests of Alcohol/Gasoline Blends," (memorandum for record) U.S. Army Mobility Equipment Research and Development Command, 23 April 1979.

Meeting with Eugene Ecklund, Alcohol Fuels Group, engineering fleet tests, and commercial prices for ethanol and methanol.

61. Moses, C.A., et al, "Engine Experiments With Alcohol/Diesel Fuel Blends," proceedings of the Third International Symposium on Alcohol Fuels Technology, May 29-31, 1979.

A study of the combustion and performance of alcohol/diesel fuel blends was conducted and potential use and associated problems were discussed.

62. Mundo, K.J., Wehner, H., "The Production of Methanol From Wood: Processes, Forestry, and Economics," Uhde GmbH, Third International Symposium on Alcohol Fuels Technology, May 1979.

The technology, investment, and operating costs for development of methanol production from artificial forestry is discussed.

63. Naegeli, D.N., "Dissociated Methanol as an Engine Fuel," Southwest Research Institute, June 15, 1978.

Methanol can be pyrolyzed to provide hydrogen for use as fuel. Dissociation mechanisms, equations of state, equilibrium. Tables and graphs.

64. Naegeli, D.N., Bowden, J.N., "Comments on 'Methanol Additive to Gasoline'," Southwest Research Institute re: Quaternion Chemical Industries, cover letter 29 January 1981 by S.J. Lestz.

Advantages and disadvantages of methanol and ethanol, sources availability, and processing.

65. Nagalingam, B., Saidhar, B.L., Panchepakesan, W.R., Gopalakrishnan, K.V., Murthy, B.S., "Surface Ignition Initiated Combustion of Alcohol in Diesel Engines-A New Approach," Indian Institute of Technology, Society of Automotive Engineers SAE Technical Paper Series No. 800262, 1980.

Test diesel engine used in approach of force igniting methanol with a heated and insulated surface.

66. Naman, T.M., Allsup, J.R., "Exhaust and Evaporative Emissions From Alcohol and Ether Fuel Blends," U.S. Department of Energy, SAE Technical Paper No. 800858, 1980.

Study conducted at BETC to evaluate potential fuel extenders-in-gasoline as to fuel economy, exhaust emissions, and evaporative emissions.

67. Nersasian, A., "The Use of Toluene/Isooctane/Alcohol Blends to Simulate the Swelling Behavior of Rubbers in Gasoline/Alcohol Fuels," E.I. du Pont de Nemours and Company, Society of Automotive Engineers SAE Technical Paper Series No. 800790, 1980.

Swelling of elastomers was achieved with high accuracy using a homemade blend to simulate gasoline alcohol blends.

68. Nichols, R.J., et al, "Ford's Development of a Methanol-Fueled Escort," proceedings of the Fifth International Alcohol Fuels Technology Symposium, Auckland, New Zealand, Vol. II, May 1982.

California Energy Commission established a program to test suitability of alcohol fuels and facilitate development of alcohol vehicle configurations. Specific goals are for development of alcohol vehicles which meet the 1982 CA emission standards, to achieve 27.5 MPG on a gasoline energy-equivalent basis, and provide a driving range of 200 miles.

69. Nichols, R.J., "Modification of a Ford Pinto for Operation on Methanol," State of California, Third International Symposium on Alcohol Fuels Technology, May 1979.

SI engine and fuel system modifications made to accomodate methanol fuel and optimize vehicle performance.

70. No Author, "Alcohol/Aviation Pioneers Report Methanol Big Success in 6,000-Mile Test," Alcohol Week, 5 December 1980.

Super Piper Cub was flown on a methanol formula. Results were high efficiency and power, and good performance of high altitude.

71. No Author, "Alcohol Fuels Program Plan," U.S. Department of Energy Office of the Under Secretary Task Force on Alcohol Fuels, March 1978.

Program goals, objectives, and milestones based on alcohol supply, production, technical and other issues concerning alcohol for use as fuel.

72. No Author, "Alternative Fuels Utilization Report," U.S. Department of Energy, No. 7, January 1981.

AFUP state-of-the-art update, investigations using alcohol/gasoline blends, neat alcohols, and diesel testing.

73. No Author, "Alternative Transportation Vehicles and Fuels for the U.S. Air Force," Feasibility Assessment, Phase I, Volume II, Mobile Systems Directorate, Eastern Technical Division, The Aerospace Corporation, for U.S. Department of Defense and U.S. Department of Energy, October 1981.

Chapter on alcohol availability and interest in production as motor fuel. Chapter on environmental and safety factors.

74. No Author, "A Report on VITON® in Automotive Fuel Systems," E.I. du Pont de Nemours and Company, April 14, 1980.

The role and performance of VITON® elastomer in storage, delivery, and mixing components. Effects of gasoline aromatic content, alcohol/gasoline blends, other additives and sour fuel are also discussed.

75. No Author, "A Task for the 80's: U.S. Construction of Methanol-Producing Barges," Litton Industries, March 10, 1981.

Litton Industries proposes building methanol-producing barges. These barges would be capable of converting vast supplies of wasted natural gas into methanol for use in a variety of applications.

76. No Author, "A Technical Assessment of Alcohol Fuels," Alternate Fuels Committee of the Engine Manufacturers Association, Society of Automotive Engineers, Technical Paper No. 820261, 1982.

The use of alcohol as fuel for internal combustion engines. Methods of production, economic considerations and discussion of properties, methods of engine introduction, emissions, and safety factors are presented.

77. No Author, "Baltimore Beginning Methanol Blend Fleet Tests in 2-4 Weeks," Alcohol Week, 3 (25) page 1, June 21, 1982.

As part of the Urban Consortium's energy task force activities, the City of Baltimore will operate six AMC Concord cars on a 90 percent methanol + 10 percent unleaded gasoline blend for about a year under DOE program.

78. No Author, "Conoco Starts Fleet Testing Neat Methanol; Planning Blend Tests for '82," Alcohol Week, Vol. 2, No. 51, 21 December 1981.

Fleet testing of neat methanol to be compared with fuel/methanol blends as part of a strategy for decision of how methanol should be used as a vehicle fuel.

79. No Author, "Department of Defense Use of Alcohol Fuels," U.S. Department of Defense, Energy and Water Resources Laboratory, 21 November 1980.

Mostly performance and compatibility of ethanol/gasoline blends, some mention of methanol.

80. No Author, "Department of Energy Position Paper on Alcohol Fuels," U.S. Department of Energy, Office of the Under Secretary Task Force on Alcohol Fuels, March 1978.

Department of Energy position on alcohol as fuel as part of the Alcohol Fuels Program. Major issues and end use considerations, time frame considerations, considerations for resolutions.

81. No Author, "Federal Agency and Department Alcohol Fuels Programs," U.S. National Alcohol Fuels Commission, March 1980.

Description of all current alcohol fuels programs in the federal agencies and departments is presented.

82. No Author, "Ford's Better Idea: A Propane-Powered Car," Chicago Tribune, June 8, 1982.

Ford has begun building compact Granadas that run strictly on propane. Propane is both cheaper and more abundant than gasoline, with estimates up to a 500,000 barrel-a-day worldwide surplus by 1985.

83. No Author, "Fossil and Synthetic Fuels-Miscellaneous-Part I," Hearings Before the Subcommittee on Fossil and Synthetic Fuels of the Committee on Energy and Commerce-House of Representatives Ninety-seventh Congress, U.S. Government Printing Office, 1981.

Hearings on GSA studies for fuel conservation presented by various U.S. representatives.

84. No Author, "Meeting of Coordinating European Council for the Development of Performance Tests for Lubricants and Engine Fuels," Engine Fuels Technical Committee, held in Stockholm 9 April 1981.

Council's acknowledgement and effort to deal with problems associated with oxygenated and other fuels.

85. No Author, "Methanol Can Be Converted to Gasoline," based on SAE Paper 811403 by F.B. Fitch, 1981.

High octane gasoline can be produced from the dehydration of methanol using Mobil Oil's MTG process. Gasoline properties are discussed.

86. No Author, "Methanol Fuel Use Urged as Way to Trim Surplus," Oil and Gas Journal, p. 82, June 7, 1982.

Until the number of vehicles using methanol keeps pace with the current methanol surplus, suggestions are made for possible methanol uses. Predicted developments of methanol in the fuel market are covered.

87. No Author, "Methanol Can Cause 5 Times As Much Engine Wear As Gasoline," Southwest Research Institute, Alcohol Week, pp 7-8, 9 November 1981.

Speculation on parameters which help to cause wear in alcohol-fueled SI engines. Fleet test, possible critical oil temperature, need for further research.

88. No Author, "North Carolina Embarks on Methanol Testing; Begins With Dual-Tank Process," Alcohol Week, Vol. 2, No. 51, 21 December 1981.

A new process is being tested by North Carolina state government in an effort to introduce methanol-powered cars into the state vehicle fleet.

89. No Author, "Oxinol : Gasoline Blending Component," Oxirane Corporation, Houston, TX, 1979.

Technical bulletin on "Oxinol " (50 percent t-butanol, 50 percent methanol) oxygenated blending component, octane improver up to 5 vol%. Emission testing, driveability, water tolerance, blending vapor pressure, fuel system compatibility, toxicological data.

90. No Author, "Passenger Car Fuel Economy in Short Trip Operation," prepared by Gulf Research and Development Company for U.S. Department of Energy, July 1978.

Purpose is to assess benefits from gasoline blended with alcohol in short trip fuel economy. Test procedure using all-weather chassis dynamometer. Test results had high accuracy.

91. No Author, "Project Planning Document Highway Vehicle Alternative Fuels Utilization Program (AFUP)," U.S. Department of Energy, July 1979.

Specific criteria and guidelines for the evaluation and development of alternative fuels for highway vehicles. Mechanism for implementation of AFUP is outlined.

92. No Author, "Senate Bill 620: Alcohol Fuels Program," California Energy Commission, staff report, January 1981.

Paper describes a demonstration program to explore practicality, efficiency, and cost effectiveness for ethanol from biomass undertaken by various participants. Status of fleet testing by participants is also given.

93. No Author, "Southwest Research Develops Additive to Cut Methanol Engine Wear in Half," Southwest Research Institute, Synfuels, p. 5, 12 December 1980.

Additive forms a protective barrier between the combustion product formic acid and engine metal surfaces. Also, damage done to the engines diminishes in proportion to the concentration of methanol.

94. No Author, "SRI Very Pessimistic About Neat Methanol Blends," Alcohol Week, Volume 3 No. 1, 4 January 1982.

Distribution and technical problems, if not solved, will prohibit existing marketers of gasoline to adopt methanol blends.

95. No Author, "State Initiatives on Alcohol Fuels," United States National Alcohol Fuels Commission, August 1980.

A state-by-state compendium of laws, regulations, and other activities involving alcohol fuels. Each state also includes the name of the responsible official for further information.

96. No Author, "Status of Alcohol Fuels Utilization Technology for Highway Transportation," prepared by Mueller Associates for U.S. Department of Energy, June 1978.

Current status of alcohol utilization technology for highway transportation is reviewed. Topics covered are emissions, performance, materials compatibility, engine design, fuels characterization and environmental considerations.

97. No Author, "Status of Alcohol Fuels Utilization Technology for Stationary Gas Turbines," Mueller Associates Inc., for U.S. Department of Energy, April 1979.

Summaries of tests using full- and small-scale stationary gas turbine engines. Problem-causing characteristics of alcohols, possible solutions by engine modifications and design consideration are discussed.

98. No Author, "The Multi-Year Program Plan for the Office of Technology Development and Utilization of the Alcohol Fuels Group Program Office of the Department of Energy," Office of Technology Development and Utilization of the Alcohol Fuels Group Program Office, June 1980.

Organization and implementation plan, the role of the government, role of the Alcohol Fuel Program Office, role of the Office of Technology Development and Utilization, technology and utilization assignment. Tables, diagrams, graphs, charts.

99. No Author, "The Potential Availability of Alternative Energy Materials for Displacing Petroleum Fuels," Mueller Associates for Southwest Research Institute, Army Sponsored Contract No. DAAK70-80-C-0001, December 1981.

Tables of fuel production projections for various organizations.

100. Osler, C.T., "Canadian Scenario for Methanol Fuel," Third International Symposium on Alcohol Fuels Technology, May 29-31, 1979.

Canadian scenario to displace significant amounts of gasoline and diesel fuel with methanol fuel during the next two decades is outlined.

101. Owens, E.C., "Engine Lubricants for Use in Methanol Fueled Highway Vehicles," Southwest Research Institute, Highway Vehicle Systems, Contractors' Coordination Meeting, October 1977.

Examination of all test engine components that come in contact with engine oil after SI engine was run with neat methanol as fuel.

102. Owens, E.C., Marbach, H.W. Jr., Frame, E.A., Ryan, T.W. III, "Effects of Alcohol Fuels on Engine Wear," Interim Report AFLRL No. 133, U.S. Army Fuels and Lubricants Research Laboratory for U.S. Army Mobility Equipment Research and Development Command, October 1980.

Neat methanol and ethanol and their gasoline blends are investigated as to their effects on engine lubrication and wear. Factors promoting wear are hypothesized.

103. Owens, E.C., Marbach, H.W. Jr., Frame, E.A., Ryan, T.W. III, "Lubrication Requirements for Alcohol-Fueled Spark Ignition Engines," Southwest Research Institute, proceedings of the IV International Symposium on Alcohol Fuels Technology, Guariba, S.P., Brazil, 5-8 October 1980.

Research on the effects of alcohol on engine lubrication and wear for pure methanol, pure ethanol and methanol/or ethanol/unleaded gasoline blends.

104. Owens, E.C., Naegeli, D.W., "Use of Low Molecular Weight Alcohols as Diesel Fuel Extenders (Proposal)," U.S. Army Fuels and Lubricants Research Laboratory, for U.S. Army Mobility Equipment Research and Development Command, April 1978.

History of use, chemistry for emulsions, combustion character.

105. Patterson, D.J., "Solving Alcohol Fuel Problems by Engine Modification," University of Michigan, Highway Vehicle Systems, Contractors' Coordination Meeting, October 1977.

In-depth study of problems and solutions for retrofitting older vehicles to provide guidelines for future engine design to accommodate alcohol fuel.

106. Peach, J.D., "Concerns Over the Department of Energy's (DOE's) Program and Organization for Developing and Promoting the Use of Alcohol Fuels (EMD-80-88)," Letter to Secretary of Energy Charles W. Duncan, from U.S. General Accounting Office, July 22, 1980.

Potential of alcohol fuels, present technology, and problems with legislation are discussed.

107. Pefley, R., "Alcohol Fuels for Automobiles," University of Santa Clara, Highway Vehicle Systems Contractors' Coordination Meeting, September 1979.

Evidence of steady-state engine operation provides basis for a study in optimization strategy for methanol-fueled vehicles.

108. Pefley, R., "Engine Improvement Possibilities and Environmental Consequences of Alcohol Usage," University of Santa Clara, Highway Vehicle Systems Contractors' Coordination Meeting, October 1978.

Changes in camshaft design, compression ratio increase, carburetor design, and fuel composition were investigated to improve alcohol-fueled engine performance.

109. Pefley, R., "Methanol Utilization," University of Santa Clara, Highway Vehicle Systems Contractors' Coordination Meeting, October 1977.

Performance and emission character of methanol compared with that of gasoline. Adjustments and modification of fuel/air ratio, process modeling, lean burning were made to aid in study. Performance and engine wear as well as environmental impact is considered.

110. Petterson, E., "Introduction of Alternative Motor Fuels," Swedish Commission for Oil Substitution, DsI 1980:20, Liberforlag 1980.

Prerequisites necessary for synthetic/alternate fuel introduction and proposals for action.

111. Fischinger, F.F., "A New Way of Direct Injection of Methanol in a Diesel Engine," University Aachen, Third International Symposium on Alcohol Fuels Technology, May 1979.

Ignition spray conception for dual-fueling a diesel engine with methanol. Certain engine parameters were changed to optimize the combustion system.

112. Pischinger, G., Pinto, N.L.M., "Experiences With the Utilization of Ethanol/Gasoline and Pure Methanol in Brazilian Passenger Cars," Third International Symposium on Alcohol Fuels Technology, May 29-31, 1979.

Use of ethanol in Brazilian cars is explained; reasoning behind ethanol's choice consumption and test results and quality information are presented.

113. Rains, W.A., Williams, R., "Methanol--Current Situation and Future Impact on Fuels," presented at 1982 NPRA Annual Meeting in San Antonio, TX 20-23 March 1982.

The current and future uses and needs for methanol are discussed. Potential uses for methanol include use in gasoline/methanol blends as well as an octane improver and as a gasoline extender.

114. Rajas, S., "Factors Influencing Cold Starting of Engines Operating on Alcohol Fuel," Southern Illinois University, Third International Symposium on Alcohol Fuels Technology, May 1979.

Paper examines various fuel, engine, and ignition system parameters that influence cold starting and warmup drivability for engines fueled with alcohol and alcohol/gasoline blends.

115. Raymond, R.D. "Project Plan for Reliability Fleet Testing of Alcohol/Gasoline Blends," prepared by the Aerospace Corporation for U.S. Department of Energy, presented at the Highway Vehicle Systems Contractors Coordination Meeting, October 23-25, 1979.

Report addresses fuels and vehicles representative of what industry would most likely provide if alcohol/gasoline blends significantly penetrate the U.S. market.

116. Reed, T.B., Lerner, R.M., "Methanol: A Versatile Fuel for Immediate Use," Science, Vol. 182 No. 4119, 28 December 1973.

Methanol as a viable fuel. Properties, combustion performance, manufacture, recommendations for implementation.

117. Rogerson, P.L., "Imperial Chemical Industries' Low Pressure Methanol Plant," Imperial Chemical Industries, Ltd., Teesside, England, Chemical Engineering Progress Symposium Series, Vol. 66, No. 98, pp 28-34, May 1969.

Process used in methanol synthesis plant is described. Associated problems considered valuable for future designs.

118. Ryan, T.W. III, Callahan, T.J., Likos, W.E., Moses, C.A., Dodge, L.G., "Alternative (Hybrid) Fuels for Highway Transportation," Final Technical Report, Vol. 1, Southwest Research Institute, San Antonio, TX, presented at DOE Contractors Coordination Meeting, Dearborn, MI, October 1981.

A three-year program to identify and assess the practicality of developing and utilizing hybrid fuels in highway vehicles. Over seventy different fuel formulations were formulated and evaluated in this program.

119. Salisbury, D.F., "Methanol Engines-Possible New Entry in the High-Mileage Race," The Christian Science Monitor, March 1981.

Advantages of use of dissociated methanol over gasoline in an automotive engine as told by Dick Passamaneck, automotive engineer.

120. Samaga, B. S., Gopalakrishnan, K. V., Murthy, B. S., Pefley, R. K., Bechtold, R. L., "Evaluation of Methanol for Reduced Exhaust Emissions in a Single-Cylinder Research Engine," Karnataka Regional Engineering College, Indian Institute of Technology, University of Santa Clara, and U.S. Department of Energy, Third International Symposium on Alcohol Fuels Technology, May 1979.

Examination of the influence of different operating engine parameters on the formation of NO_x, CO, unburned fuel and aldehydes when the engine is fueled by methanol and methanol-water mixtures.

121. Schreiner, M., "Research Guidance Studies to Assess Gasoline From Coal by Methanol-to-Gasoline and Sasol-Type Fischer-Tropsch Technologies," Mobil Research and Development Corporation, Princeton, NJ, August 1978.

Technical and economic comparison for manufacture of quality gasoline. It is concluded that the methanol conversion process is superior.

122. Seiffert, U., "Mid-Term Prospects for the Use of Alcohols as Motor Vehicle Fuels," Volkswagenwerk, Third International Symposium on Alcohol Fuels Technology, May 29-31, 1979.

Brief discussion of the world energy resource situation; concludes that non-petroleum-based fuels will be needed for automobiles in the foreseeable future.

123. Shackson, R.H., Leach, H.J., "Methanol as an Automotive Fuel," report of Workshop on Implementation Strategies and Research Needs, November 1, 1981.

Implementation strategies for market introduction, technical issues including safety, and distribution.

124. Shurtum, R.P., Davison, R.R., Anthony, R.G., "Conversion of Coal-Based Methanol to Gaseous Fuel Proposed," Texas A&M University, Oil and Gas Journal, 31 October 1977.

Theory, design, and projected costs of converting coal-derived methanol to a mixture of fuel gases.

125. Shirvani, H., Goering, C.E., Sorenson, S.C., "Performance of Alcohol Blends in Diesel Engines," University of Illinois, Society of Automotive Engineers SAE Technical Paper Series No. 810681, 1981.

Four-stroke diesel engine tested with alcohol-containing fuel blends. Results discussed.

126. Smith, K.D., "Methanol: A California Perspective," Synthetic Fuels Office, California Energy Commission, Sacramento, CA, prepared for Workshop in Implementation Strategies and Research Needs, Detroit, MI, September 15-16, 1981.

Issues related to the introduction of methanol as a major transportation fuel: resources bases, location, storage and distribution, competitive price, engine efficiency, and exhaust emissions.

127. Sperling, D.A., "National Methanol Systems: Prospects and Problems," University of California, Davis, CA, prepared for A Workshop on Implementation Strategies and Research Needs, September 15-16, 1981.

A development path for marketing methanol as a fuel is outlined. It is designed to stimulate a large and rapid production build-up by analyzing supply and demand, and using market penetration strategies.

128. Stamper, K., "Ethanol and Methanol Fleet Operation," U.S. Department of Energy, Highway Vehicle Systems Contractors' Coordination Meeting, October 1978.

Fleet test for driveability, economy, and exhaust emissions. Physical property studies for volatility, octane character and others were also undertaken.

129. Stamper, K., "50,000 Mile Methanol/Gasoline Blend Fleet Study-A Progress Report," U.S. Department of Energy, Third International Symposium on Alcohol Fuels Technology, May 1979.

Data from chassis dynamometer tests show differences in fuel economy and in emission levels of CO, NO_x, unburned fuel, methanol, and aldehydes. Vehicles were run on 10 percent methanol (Indolene blends and pure Indolene). Observations on drivability and material compatibility.

130. Stiles, A.B., "Methanol, Past, Present, and Speculation on the Future," University of Delaware, AIChE Journal, Vol. 23, No. 3, pp 362-375, May 1977.

Overview of methanol technology from historical standpoint and how it relates to the present and possibly the future. Ingredients, gas generating techniques, processing, and equipment are discussed.

131. Strelzoff, S., "Methanol Technology and Economics," American Institute of Chemical Engineers, Chemical Engineering Progress Symposium Series, No. 98, Vol. 66, 1970.

Chemical reactions, chemical equilibria and factors affecting equilibria, and kinetics involved in methanol synthesis. Also discussed are fundamentals and means of manufacture, and catalysis which are given economic consideration.

132. Terzoni, G., Pea, R., Ancillotti, F., "Improvement of the Water Tolerability of Methanol-Gasoline Blends," Association for Scientific Research of ENI Group Companies, Third International Symposium on Alcohol Fuels Technology, May 1979.

Behavior of blends of methanol and hydrocarbons examined at different temperatures for water tolerance. The solubilizing of oxygenated compounds evaluated, including higher alcohols.

133. Unzelman, G.H., "Value of Oxygenates in Blending, Octane Improvements for Mogas Are Appraised," Ethyl Corporation, (LA) Oil and Gas Journal Report, pages 77-84, 1 June 1981.

Update of trends in process technology and feedstocks. Possibilities and potentials of alcohol blends crude conservation, octane improvement economics.

134. Wagner, T.O., Gray, D.S., Zarah, B.Y., Kozinski, A.A., "Practicality of Alcohols as Motor Fuel," Amoco Oil Company, Society of Automotive Engineers SAE Paper Series No. 790429, 1979.

Properties of methanol and ethanol, cost of manufacture, investment required, energy balance, distribution, and product quality considerations.

135. Westbrook, C.K., "Modeling of Flame Properties of Methanol," Lawrence Livermore Laboratory and Princeton University, Third International Symposium on Alcohol Fuels Technology, May 1979.

Flame speed or propagation rate, flame thickness, etc. of methanol vapor/air mixtures investigated. Mechanisms and kinetics are given for illustrative purposes. Effects of temperature, pressure, and equivalence ratio are discussed.

136. White, H.M., "DOE Reliability Fleet Test Program for Alcohol/Gasoline Fuels," The Aerospace Corporation, Highway Vehicle Systems Contractors' Coordination Meeting, September 1979.

Fleet tests to demonstrate commercial readiness of alcohol fuels.

137. Yamamoto, T., "Methanol as a Fuel," Sekiyu Gakkaishi, Vol. 16, No. 10, pp 825-8, 1974.

Drawbacks and uses for substituting methanol for petroleum fuel. Drawbacks include low heat of combustion and water solubility while potential uses for small-scale electric generation and in boilers are discussed.

138. Myers, M.A., "Assessing the Feasibility of Converting Commercial Vehicle Fleets to Use Methanol as an Offset in Urban Areas (PAD-82-39)," GAO Report B-207490, June 11, 1982.

The results of a GAO study on the economical feasibility of vehicle conversion to methanol fueling are reported.

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