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GAO

Briefing Report to the Chairman, Subcommittee on Fossil and Synthetic Fuels, Committee on Energy and Commerce, House of Representatives

October 1986

ALTERNATIVE FUELS

Status of Methanol Vehicle Development

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Resources, Community, and
Economic Development Division

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October 17, 1986

The Honorable Philip R. Sharp
Chairman, Subcommittee on Fossil
and Synthetic Fuels
Committee on Energy and Commerce
House of Representatives

Dear Mr. Chairman:

This briefing report concludes a series of three reports responding to your May 7, 1984, request for information on the development of methanol as an alternative fuel. In May 1985 we issued a report entitled Federal and State Methanol Fuel Projects, Coordination, and State Tax Incentives (GAO/RCED-85-97). In April 1986 we issued a fact sheet entitled Alternative Fuels: Potential of Methanol as a Boiler or Turbine Fuel (GAO/RCED-86-136FS). We also issued Removing Barriers to the Market Penetration of Methanol Fuels (GAO/RCED-84-36) in response to an earlier request.

This briefing report presents information we provided to your staff during a July 11, 1986, briefing on methanol supply and the status of methanol vehicle development in the United States. Nationally, vehicle fuel use accounted for less than 1 percent of the 1.1 billion gallons of methanol produced in 1985. If used to fuel vehicles, the total domestic methanol production capacity could meet less than 1 percent of automotive fuel demand.

Automobile manufacturers and state and private research groups have made progress developing methanol-fueled vehicles, but further research is needed to resolve some remaining technical issues such as cold weather starting. Ford Motor Company is also experimenting with a flexible fueled vehicle that can operate on either gasoline, methanol, or various combinations of both. This vehicle could facilitate a transition to methanol vehicles. However, the lack of methanol fuel availability at the retail level and comparatively low gasoline prices are disincentives for producing methanol vehicles. Automobile manufacturers said that a transition to methanol would not be economically viable until automobiles can operate on methanol as cheaply as gasoline.

Federal standards for vehicle emissions and fuel economy could influence the introduction of methanol as an alternative vehicle fuel. Several mass transit authorities are experimenting with methanol-fueled buses to reduce air pollution emissions. A review of methanol fuel health and safety issues indicated that there was no conclusive evidence that methanol is any more dangerous than gasoline. Both pose certain health and safety risks under some conditions.

We obtained information for this briefing report from discussions with and documents obtained from federal, state, and industry officials involved with methanol fuel and vehicle development.

As requested by your office, we did not obtain official agency comments on a draft of this report. We did obtain the views of cognizant officials at the Departments of Energy and Transportation and the Environmental Protection Agency during the course of our work. Their views have been incorporated into the report where appropriate. A draft of this report was also discussed with methanol vehicle experts.

As arranged with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. At that time we will send copies to interested parties and make copies available to others upon request. If you have questions about this briefing report, please contact me on (202) 275-8545.

Sincerely yours,

for James Duffus III
Associate Director

Contents

ABBREVIATIONS

CAFE	corporate average fuel economy standards
CEC	California Energy Commission
CO	carbon monoxide
DDA	Detroit Diesel Allison Division, General Motors Corporation
DOT	U.S. Department of Transportation
EPA	Environmental Protection Agency
FFV	flexible fuel vehicles
GAO	General Accounting Office
g/bhp-hr	grams per brake horsepower-hour
GM	General Motors Corporation
g/mi	grams per mile
HC	hydrocarbons
MAN	Maschinenfabrik Augsburg-Nurnberg A.G.
mpg	miles per gallon
NO_x	Oxides of nitrogen
RCED	Resources, Community, and Economic Development Division
UMTA	Urban Mass Transportation Administration

SECTION 1

OBJECTIVES, SCOPE, AND METHODOLOGY

OBJECTIVES, SCOPE, AND METHODOLOGY

° OBJECTIVES

--PROVIDE INFORMATION ON METHANOL SUPPLY AND THE STATUS OF METHANOL VEHICLE (AUTOMOBILES, LIGHT-DUTY TRUCKS, AND BUSES) DEVELOPMENT IN THE UNITED STATES.

--DISCUSS THE FEDERAL GOVERNMENT'S ROLE IN THE INTRODUCTION OF NEW FUELS AND HOW THIS ROLE MIGHT RELATE TO THE INTRODUCTION OF METHANOL.

° SCOPE

--THIS BRIEFING REPORT DISCUSSES METHANOL SUPPLY, THE INTRODUCTION OF NEW FUELS, AND THE TECHNICAL, ENVIRONMENTAL, AND SAFETY ASPECTS OF USING METHANOL FUEL IN VEHICLES.

° METHODOLOGY

--WE CONSULTED WITH AND OBTAINED INFORMATION FROM VEHICLE EXPERTS AND MANUFACTURERS, METHANOL PRODUCERS, AND FEDERAL AND STATE OFFICIALS.

--WE VISITED AND OBTAINED INFORMATION FROM METHANOL AUTOMOBILE AND BUS FLEET OPERATORS.

--WE REVIEWED CONGRESSIONAL LEGISLATION AND TESTIMONY, PUBLICATIONS, DOCUMENTS, AND REPORTS RELATING TO METHANOL.

--METHANOL FUEL AND VEHICLE EXPERTS REVIEWED A DRAFT OF THIS REPORT FOR TECHNICAL VALIDITY.

This section discusses the objectives we agreed to address, the scope of our work, and the methodology we used to obtain information to achieve our objectives.

OBJECTIVES

In a May 7, 1984, request, the Chairman, Subcommittee on Fossil and Synthetic Fuels, House Committee on Energy and Commerce, asked us to examine several aspects of methanol fuel use. In response to portions of the request, we issued a report entitled Federal and State Methanol Fuel Projects, Coordination, and State Tax Incentives (GAO/RCED-85-97, May 1985) and a fact sheet entitled Alternative Fuels: Potential of Methanol as a Boiler or Turbine Fuel (GAO/RCED-86-136FS, April 1986). We also issued Removing Barriers to the Market Penetration of Methanol Fuels (GAO/RCED-84-36) in response to an earlier request.

This briefing report responds to the remainder of the request which asked us to (1) provide information on the status of the development of methanol vehicles in the United States and (2) discuss the federal government's role in introducing diesel and lead-free gasoline into the transportation sector and how that role might relate to introducing methanol. As agreed during subsequent discussions with the Chairman's office, this report also discusses methanol supply and several environmental and safety aspects of methanol vehicles.

SCOPE

Within the area of methanol vehicle technology, we dealt only with the use of pure, or nearly pure, methanol (usually called methanol fuel or M85) in vehicles. This fuel contains about 15 percent gasoline,[1] to address safety concerns and aid cold starting. We did not examine the use of low-level (3 to 5 percent) methanol blends in gasoline because these blends are being marketed for use in existing vehicles. We also did not evaluate the economic viability of methanol as a vehicle fuel compared with gasoline and diesel.

METHODOLOGY

To obtain information on methanol supply, we relied on a May 1985 analysis of the methanol industry prepared by the Department of Commerce and used data on imports supplied by the Census Bureau, Department of Commerce. We also contacted and obtained information from methanol producers.

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[1]The gasoline is a specific type of premium lead free.

To understand the federal government's role in introducing lead-free gasoline and diesel fuels and how that role might relate to introducing methanol, we reviewed pertinent legislative documents; congressional testimony and transcripts; automotive industry publications; and federal agencies' documents, rules and regulations, policies, programs, studies, reports, and program guidelines. We interviewed fuel and vehicle industry officials to obtain their views on factors affecting the introduction and use of lead-free gasoline and diesel fuel and on the prospects for methanol fuel demand as a result of gasoline lead content phasedown.

To obtain information on methanol vehicle development, we interviewed and obtained information from vehicle experts at Ford Motor Company world headquarters in Dearborn, Michigan; General Motors (GM) Technical Center in Warren, Michigan; Detroit Diesel Allison Division of GM in Romulus, Michigan; and the Mechanical Engineering Department, University of Santa Clara, Santa Clara, California. We also interviewed and obtained documents, publications, and studies from cognizant federal officials at the Environmental Protection Agency's (EPA's) Motor Vehicle Emissions Laboratory in Ann Arbor, Michigan; the Department of the Army's Belvoir Research and Development Center at Ft. Belvoir, Virginia; and the Departments of Energy and Transportation in Washington, D.C.

To obtain information on methanol automobile and bus fleet operations, we visited the California Energy Commission in Sacramento, California; the Bank of America fleet operations headquarters in Concord, California; the Golden Gate Transit District in San Rafael, California; and the Presidio Army Base in San Francisco, California. To obtain information on methanol fuel safety, we relied on technical reports and journals. We obtained information from EPA, conference proceedings, and experts in government and industry. In addition, we contacted state agencies and reviewed other publications, documents, reports, studies, and literature on methanol supply, vehicle technology, safety, and environmental and regulatory considerations of using methanol as a vehicle fuel. The government, industry, and other organizations we contacted are listed in appendix I.

Information for this briefing report was gathered between March 1985 and May 1986. A draft of this report was reviewed for technical validity by Dr. Roberta Nichols, Principal Research Engineer, Engine Research Department at Ford Motor Company; Dr. Richard Pefley, Professor of Mechanical Engineering, University of Santa Clara; and Mr. Michael Jackson, Acurex Corporation, Energy and Environmental Division.

SECTION 2

METHANOL SUPPLY

METHANOL SUPPLY

- IN 1985 THE UNITED STATES PRODUCED ABOUT 1.1 BILLION GALLONS OF METHANOL, MOSTLY FROM NATURAL GAS. LESS THAN ONE-HALF OF 1 PERCENT WAS USED TO FUEL METHANOL VEHICLES.

- IF THE 1986 U.S. OPERATIONAL METHANOL PRODUCTION CAPACITY OF ABOUT 1.2 BILLION GALLONS PER YEAR WAS USED FOR FUEL, IT WOULD BE EQUIVALENT TO LESS THAN 1 PERCENT OF THE DOMESTIC AUTOMOTIVE FUEL DEMAND.

- THE UNITED STATES HAS SUFFICIENT COAL TO PRODUCE ENOUGH METHANOL TO REPLACE GASOLINE. HOWEVER, TECHNOLOGY AND ECONOMICS FAVOR CONTINUED NEAR-TERM METHANOL PRODUCTION FROM NATURAL GAS.

- METHANOL FUEL IMPORTS HAVE INCREASED IN RECENT YEARS.

This section defines methanol and discusses United States and world methanol supply. Topics discussed include methanol production and uses and imports.

WHAT IS METHANOL?

Methanol (methyl alcohol) is a clear, colorless, flammable liquid with a mild odor at ambient temperature.[1] The general public often confuses methanol with methane because the names are similar. While similar in chemical composition, methane (the primary component of natural gas) and methanol (commonly found in automobile windshield washer and fuel line antifreeze) are distinct chemical entities. However, methane, or natural gas, is the most commonly used feedstock for producing methanol. Methanol can also be produced from coal and other raw materials, such as wood. Methanol is sometimes called wood alcohol because wood was the prevalent raw material used for methanol production in the early 1900's. Appendix II compares methanol, gasoline, and diesel fuels.

METHANOL PRODUCTION AND USES

According to chemical industry figures, 1985 world methanol production capacity was about 6 billion gallons. In 1985 the United States produced about 1.1 billion gallons of methanol. Total operational U.S. annual methanol production capacity is about 1.2 billion gallons. The chemical industry used most of the methanol production. Methanol used as a fuel accounted for less than one-half of 1 percent of 1985 U.S. methanol production.

If a transportation fuel market develops for methanol, operational U.S. production capacity would meet less than 1 percent of domestic automotive fuel demand. In 1985 about 100 billion gallons of gasoline were used in the United States. Because methanol has a lower energy content than gasoline, experts estimate that about 1.8 gallons of methanol are required to replace 1 gallon of gasoline for vehicle fuel use. Therefore, to replace gasoline in the United States with methanol would require about 180 billion gallons per year. Assuming no imports, providing 180 billion gallons of methanol per year would require a 15,000-percent growth over existing U.S. methanol production capacity of 1.2 billion gallons.

Most methanol production uses natural gas as its feedstock; however, coal is a potential raw material for methanol production. Various studies indicate that the United States has enough recoverable coal reserves to produce a sufficient amount of methanol to replace gasoline for about 100 years and still meet a doubling of demand for coal for other uses. However, technology and economics favor continued near-term methanol production from natural gas. Estimates of the comparative cost of coal and

[1]Ambient temperature refers to the temperature of the surrounding environment.

Table 2.1: Methanol Imports for Fuel Purposes

Year	Source country	Quantity (gal.)	Customs value	Average value per gal.
1980	Canada	28,661	$ 13,227	$ .46
1981	Canada	539,871	$ 351,836	$ .65
1982	Canada	8,376,237	$ 4,434,053	
	Libya	300,000	139,841	
	Total	8,676,237	$ 4,573,894	$ .53
1983	Canada	10,751,071	$ 4,295,103	
	Mexico and other	77,205	28,000	
	Total	10,828,276	$ 4,323,103	$ .40
1984	Trinidad	11,439,123	$ 3,874,825	
	Canada	10,363,013	3,237,512	
	Mexico	540,151	174,798	
	New Zealand	175,537	46,782	
	FR Germany	4,671	6,878	
	Total	22,522,495	$ 7,340,795	$ .33
1985	Canada	12,720,917	$ 3,719,445	
	Trinidad	8,142,039	3,318,014	
	Yugoslavia	5,255,877	2,563,599	
	Italy	4,939,080	1,754,054	
	Libya	4,676,457	1,657,866	
	Bahrain	4,220,296	1,466,034	
	Netherlands	2,320,240	1,305,403	
	Saudi Arabia	1,996,000	618,052	
	United Kingdom	1,662,000	800,714	
	Romania	555,436	416,577	
	Total	46,488,342	$17,619,758	$ .38
1986 Jan.-Mar.	Canada	5,075,594	$ 1,326,024	
	Malaysia	2,319,090	934,115	
	Yugoslavia	1,842,848	1,500,498	
	New Zealand	2,560,263	1,232,147	
	Total	11,797,795	$ 4,992,784	$ .42

Source: Census Bureau, Trade Information Office, Department of Commerce.

natural gas derived methanol vary, however; methanol from coal is consistantly more expensive and the technology is less developed.

METHANOL IMPORTS

In 1985, the United States imported about 46.5 million gallons of methanol for fuel purposes. As shown in table 2.1, methanol fuel imports have increased in recent years. During this time new methanol production facilities were completed abroad, some partially owned by U.S. companies. Several U.S. methanol producers built new production facilities abroad because they were able to obtain assured supplies of natural gas at attractive prices.

Natural gas-rich, less-developed countries have a growing interest in methanol production as a means of earning foreign exchange. Many countries in the Far East and Mid-East have natural gas supplies sufficient to vastly increase methanol production without significantly affecting their natural gas reserves. Despite currently depressed methanol prices and oversupply, about 2 billion gallons of new foreign capacity are expected to come on line by 1990. According to a May 1985 Department of Commerce report on the international competitiveness of the U.S. methanol industry, many of these producers appear willing to price their methanol at any level in order to sell their total production. Methanol prices in the last quarter of 1985 at 37 to 45 cents per gallon just barely covered the operating costs of methanol production plants.

Natural gas is coproduced with oil in many areas of the world. In countries unable to make use of natural gas domestically, the main alternatives are to flare or burn the natural gas, or produce liquefied natural gas or methanol. In many cases, the high capital costs of liquefied natural gas processing, shipping, and handling has shifted attention to methanol production.

Flared natural gas, together with natural gas not associated with oil production, in less-developed countries is likely to provide the primary raw material for the bulk of methanol production capacity expansion in the near term. Data from table 2.2 show that flared natural gas has the potential to produce about 29 billion gallons of methanol per year. This is enough methanol to fuel about 36 million automobiles,[2] or roughly one-third of the automobiles operating in the United States.

[2]Assuming 12,000 miles per year per automobile and 15 miles per gallon of methanol.

Table 2.2: Potential New Methanol Production From Flared Natural Gas[a]

Country	Flared gas (billion cubic ft./yr.)	Potential methanol production (billion gal./yr.)
Saudi Arabia	903	8.75
Nigeria, Cameroons	568	5.35
Bahrain	272	2.43
Iran	272	2.43
Mexico	251	2.43
Algeria	238	2.19
Indonesia	222	1.94
United Arab-Emirates	152	1.46
United Kingdom	149	1.22
Iraq	119	0.97
Total	3,146	29.17

[a]Reported volume only.

Source: Department of Commerce.

SECTION 3

FEDERAL ROLE IN NEW FUEL

INTRODUCTION

FEDERAL ROLE IN NEW FUEL INTRODUCTION

- THE AVAILABILITY OF LEAD-FREE GASOLINE WAS MANDATED BY EPA TO PERMIT THE USE OF CATALYTIC CONVERTERS TO REDUCE CARBON MONOXIDE, HYDROCARBONS, AND NITROGEN EMISSIONS.
- THE USE OF DIESEL FUEL IN AUTOMOBILES WAS INFLUENCED BY AUTOMOBILE MANUFACTURERS' NEED TO COMPLY WITH FEDERAL AUTOMOTIVE FUEL ECONOMY STANDARDS.
- EXHAUST EMISSION AND FUEL ECONOMY STANDARDS COULD INFLUENCE METHANOL FUEL USE.
- THE FURTHER REDUCTION OF GASOLINE'S LEAD CONTENT MANDATED BY EPA IS UNLIKELY TO HAVE AN IMPACT ON METHANOL FUEL MARKETING.

This section describes the federal government's involvement in introducing new fuels. Discussed is the federal government's role in introducing lead-free gasoline and diesel fuel in automobiles, and what that role might be regarding the introduction of methanol.

INTRODUCTION OF LEAD-FREE GASOLINE AND DIESEL FUELS

Lead-free gasoline use proliferated in the mid-1970's, and diesel fuel began to penetrate the automobile market during the late 1970's. Increased availability and use of lead-free gasoline was largely a result of federal actions to help reduce automotive exhaust emissions. The introduction of diesel automobiles was partly a result of automobile manufacturers' efforts to comply with federal fuel economy standards regulated under the Energy Policy and Conservation Act of 1975.

Lead-free gasoline

The Clean Air Act gave EPA the authority to regulate substances in the air that endanger public health and welfare. The act prohibits the introduction of any new fuel or fuel additive for general use unless EPA waives the restriction by determining that the new fuel or fuel additive will not cause or contribute to a failure of the vehicle's emissions control system.

Available evidence in the early 1970's raised concern regarding the health effects of airborne lead. The use of leaded gasoline in automobiles and trucks was found to be the greatest source of airborne lead. Approximately 70 percent of lead added to gasoline is emitted as particulate matter. Lead exhaust emissions are estimated to account for 90 percent of total atmospheric lead. At the same time, regulations were established by EPA to comply with Clean Air Act mandates to reduce carbon monoxide, hydrocarbons, and nitrogen oxides emissions from vehicles. The catalytic converter was found to be the most effective means to comply with these regulations. However, the catalyst in these devices is quickly deactivated by lead deposits from engines running on leaded fuel. Therefore, the use of catalytic converters required lead-free gasoline.

In 1973 EPA established regulations that mandated the availability of lead-free gasoline. EPA mandated lead-free gasoline availability for two primary reasons: (1) concern regarding the public health effects of lead in the air and (2) to permit the use of catalytic pollution control devices in automobiles. These regulations required every gasoline retail outlet which exceeded a specified sales volume to make lead-free gasoline available by July 1, 1974. The 1975 model-year cars were the first equipped with catalytic emission control.

Table 3.1: Corporate Average Fuel Economy Standards for Automobiles Under the Energy Policy and Conservation Act

Model year	Standard[a] (mpg)
1978	18.0
1979	19.0
1980	20.0
1981	22.0
1982	24.0
1983	26.0
1984	27.0
1985	27.5
1986	26.0
1987	27.5

[a]The Secretary of Transportation may alter this standard between 26 and 27.5 mpg to reflect the "maximum feasible average fuel economy," but such action may be disapproved by the Congress for levels below 26.0 mpg or above 27.5 mpg. The Secretary has proposed reducing the standard again for model year 1987 and 1988.

Source: EPA.

Diesel fuel

When diesel fuel use began to proliferate in automobiles in the late 1970's, it was cheaper than gasoline. Lower fuel price and higher fuel economy for diesel compared with gasoline provided for the initial success of diesel-powered cars. The Energy Policy and Conservation Act of 1975 amended the Motor Vehicle Information and Cost Savings Act for the purpose of regulating automobile fuel economy. This act required that the corporate average fuel economy of all automobiles sold had to meet standards established by the Secretary of Transportation. These standards are shown in table 3.1. In order to help meet the more stringent fuel economy standards of the early 1980's, some manufacturers decided to use diesel engines in their larger automobiles. Diesel fuel had been used for many years in trucks and was available along truck routes.

Domestically produced diesel car sales started with a few models in 1977-78. These cars had fuel cost savings of as much as 40 percent for compacts and 25 percent for standard size cars. Sales accelerated with the addition of new models and the sharp increase in gasoline prices in the spring of 1979. As diesel automobiles increased in popularity, market forces provided incentives for increased availability of diesel fuel. By 1981 almost 7 percent of new cars sold were diesels. However, by 1984, diesel car sales dropped to 1.3 percent of new car production partly due to increased diesel fuel prices and problems with engine durability and performance.

HEAVY-DUTY ENGINE EMISSION STANDARDS

- CLEAN AIR ACT REGULATIONS THAT REDUCE NO_x AND PARTICULATE EMISSIONS FROM NEW HEAVY-DUTY DIESEL ENGINES WERE ESTABLISHED IN MARCH 1985.
- EMISSION STANDARDS FOR NEW URBAN TRANSIT BUSES COULD INFLUENCE THE USE OF HEAVY-DUTY METHANOL ENGINES.
- RESEARCH HAS NOT PRODUCED A METHOD ENABLING DIESEL ENGINES TO RELIABLY MEET THE NEW PARTICULATE EMISSIONS REGULATIONS.
- HEAVY-DUTY METHANOL ENGINES ARE CAPABLE OF MEETING STANDARDS BECAUSE METHANOL COMBUSTION PRODUCES LOW NO_x AND PARTICULATE EMISSIONS.

HEAVY-DUTY ENGINE EMISSION STANDARDS

Regulations to enforce emissions reductions mandated by the Clean Air Act from heavy-duty diesel engines were established in March 1985.[1] These regulations significantly reduce allowable emissions of NO_x and particulates from new heavy-duty diesel engines. Table 3.2 shows the regulations as they apply to urban transit buses. The means of complying with these regulations is left to the discretion of bus manufacturers.

Table 3.2: Emissions Standards for New Urban Transit Buses

Year	Nitrogen oxides	Particulates
	---(grams/brake horsepower-hour)----	
1985-87	10.7	-
1988	6.0	0.60
1991	5.0	0.10

Source: EPA.

The particulate requirements present the biggest problem for diesel engine manufacturers. Research to date has not produced an emission control method for diesel engines capable of reliably meeting this requirement. Diesel particulate traps, which capture and incinerate particulates in the exhaust, have yet to prove that they can enable the vehicle to meet these standards on a sustained basis. Because methanol combustion produces low NO_x and particulates, heavy-duty methanol engines are capable of meeting these stringent emissions standards. A representative of a diesel engine manufacturer told us that methanol engines might be needed to meet the 1991 particulate requirements for urban transit buses. However, engineering advances could occur that would enable diesel engines to meet the specified particulate limit by 1991. EPA said that much effort is currently being expended to develop reliable particulate traps capable of meeting the standards by 1991.

The bus engine situation shows similarities to the introduction of lead-free gasoline and diesel. In the case of lead-free gasoline, the automobile companies evaluated several potential means of complying with automobile emissions requirements and settled on the catalytic converter which required lead-free gasoline. Similarly, diesel automobiles were produced partly because they helped automobile manufacturers achieve fuel economy standards. Heavy-duty engine manufacturers are now evaluating several potential means of complying with emissions regulations. If they decide to use methanol engines for urban transit buses, the regulations will have had the effect of expediting methanol engine availability without prescribing or mandating their availability.

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[1] Federal Register, March 15, 1985, Vol. 50. #51 p.10606.

FUEL ECONOMY

- SEVERAL BILLS PENDING BEFORE THE 99TH CONGRESS CONTAIN FUEL ECONOMY INCENTIVES FOR PRODUCING METHANOL-FUELED AUTOMOBILES.
- THE PENDING BILLS PROPOSE THAT AUTOMOBILES CAPABLE OF USING METHANOL FUEL RECEIVE A FUEL ECONOMY RATING BASED ONLY ON THE GASOLINE PORTION OF THE FUEL.

FUEL ECONOMY

Because methanol is not currently defined as a fuel under the Motor Vehicle Information and Cost Savings Act or Department of Transportation (DOT) regulations, it is not covered by corporate average fuel economy standards (CAFE). It is not clear whether or how methanol vehicles would be incorporated into the act. The legislation gives the Secretary of Transportation the authority to include new fuels in the act. If methanol is incorporated into the act, EPA is required to determine the quantity of methanol that is equivalent to 1 gallon of gasoline for fuel economy calculations.

CAFE standards were established to conserve petroleum.[2] While the method of factoring methanol-fueled vehicles into fuel economy standards has yet to be finalized, congressional bills introduced in the 99th Congress propose that vehicles capable of using methanol fuel would have to meet fuel economy standards based only on the petroleum portion of the fuel.[3] Most methanol fuel is 85 percent methanol and about 15 percent lead-free premium gasoline. For example, a car achieving 15 miles per gallon on methanol fuel would receive a fuel economy rating of 100 miles per gallon based on its gasoline consumption. This rating would be used for the corporate average fuel economy standards.

According to the proposed legislation, the intent of these bills is to provide fuel economy incentives for manufacturers to produce methanol automobiles. In congressional testimony in June, July, and November 1985 before both House and Senate Committees, Ford and General Motors representatives reacted favorably towards a fuel economy incentive for methanol automobiles. However, the representatives indicated that while such incentives would be helpful, they alone would not be sufficient to bring about the production of methanol automobiles. For example, the Congress previously attempted to use legislated fuel economy incentives to encourage the early development and commercial production of electric automobiles. Regulations were established in 1980 providing manufacturers with fuel economy incentives to develop

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[2]H.R. Rep. No. 340, 94th Cong., 1st Sess. 86 states that "improving motor vehicle fuel economy can have a substantial impact on petroleum consumption...." Further, Section 2 of Public Law 96-425 stated that the congressional purpose of the 1980 amendment was "to amend certain Federal automobile fuel economy requirements to improve fuel efficiency, and thereby facilitate conservation of petroleum and reduce petroleum imports."

[3]H.R. 3355, 99th Congress, 1st Session; H.R. 2955, 99th Congress, 1st Session; and S. 1097, 99th Congress, 1st Session.

and produce electric automobiles.[4] However, electric automobiles have not been produced for a variety of reasons, including the lack of viable technology, higher costs compared to conventional automobiles, and the absence of market demand. In this case, fuel economy incentives were not sufficient to encourage the production of electric automobiles and may not be enough incentive for the production of methanol automobilies.

During the congressional hearings, the GM representative cautioned that a fuel economy incentive would have to be considered along with fuel price, availability, and the status of methanol vehicle technology. GM said that a fuel economy incentive would have its greatest effect only after the fuel is generally available at a favorable price relative to gasoline and after methanol automobiles have been fully developed and tested.

On the basis of available data, methanol-fueled automobiles would probably have a higher fuel cost on a dollars-per-mile basis than gasoline-fueled automobiles. Comparing fuel cost between methanol and gasoline vehicles is difficult because the cost of methanol fuel distributed on a large scale comparable to gasoline is unknown. The only fuel cost data available for comparison is from California. However, this data cannot be regarded as representative of the typical price that is likely to be charged for methanol fuel because it is shipped in small quantities from methanol plants on the Gulf coast and, therefore, carries a large incremental cost for transportation. In March 1986 methanol fuel cost about $.80 per gallon in California and regular lead-free gasoline was about $.85 per gallon. Methanol-fueled automobiles require about 1.8 gallons of fuel to travel as far as a gasoline-fueled automobile on 1 gallon of gasoline. Under these conditions, a methanol-fueled automobile would have fuel costs of about $1.44 to drive the same distance that would cost $.85 in a comparable gasoline-fueled automobile.

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[4]<u>Federal Register</u> Vol. 45 No. 144, July 24, 1980.

LEAD PHASEDOWN

- LEADED GASOLINE'S MARKET SHARE IS EXPECTED TO DECLINE AS EPA-MANDATED LEAD REDUCTION MAKES LEADED GASOLINE MORE EXPENSIVE AND AS CARS DESIGNED FOR ITS USE ARE TAKEN OUT OF SERVICE.

- WHILE IT IS TECHNICALLY FEASIBLE TO USE SOME OF THE LEADED GASOLINE DISTRIBUTION AND SALES CAPACITY FOR METHANOL FUEL, IT IS NOT LIKELY BECAUSE

  --METHANOL IS NOT EXPECTED TO BE ECONOMICALLY ATTRACTIVE COMPARED WITH GASOLINE DURING THE PERIOD FUEL COMPANIES EXPECT TO PHASE OUT LEADED GASOLINE AND

  --METHANOL-FUELED AUTOMOBILES ARE NOT EXPECTED TO BE AVAILABLE DURING THIS PERIOD.

LEAD PHASEDOWN

In March 1985, EPA took action to further reduce atmospheric lead concentration by reducing allowable lead levels in leaded gasoline. This action was taken due to evidence of significant price-induced misfueling of automobiles designed for lead-free fuel with leaded fuel and mounting evidence of negative health effects of exposure to atmospheric lead. An interim standard for leaded fuel of 0.5 gram of lead per gallon became effective July 1, 1985, and on January 1, 1986, a lower standard of 0.1 gram of lead per gallon was imposed. In addition, EPA requested comments from interested parties on a proposed complete phaseout of leaded gasoline as early as 1988.

The future of leaded gasoline is uncertain, whether phased out by EPA regulation or market forces. Since lead provides the least cost route to octane enhancement, lead phasedown will increase the cost of producing leaded gasoline and retail prices are likely to increase. Higher prices for leaded fuel will reduce the economic incentive for intentional misfueling of automobiles designed to operate on lead-free gasoline. Since almost all automobiles built after 1975 were designed to operate on lead-free fuel, it is primarily older cars that use leaded fuel. As these older vehicles are taken out of use, and as misfueling declines, the leaded gasoline market share will drop. According to oil industry experts, once leaded fuel's market share drops to about 10 percent of the gasoline market, it will no longer be profitable for many fuel companies to continue selling leaded gasoline.

According to some oil company representatives, their corporate strategy is being formulated on the assumption that by 1988 they will no longer be selling leaded fuel. The pumps, storage, and other capacity currently used for 89 octane leaded gasoline will most likely be used for an 89 octane lead-free gasoline. While it may be technically possible to use portions of the leaded gasoline distribution system for methanol, it would be necessary to replace materials susceptible to deterioration in the presence of methanol and renovate storage facilities. This would add to the cost of marketing the fuel, especially compared to an 89 octane lead-free gasoline, which would not require materials replacement. Oil company representatives said that a market for 89 octane lead-free gasoline already exists, while automobiles capable of using methanol fuel will not be available until at least the 1990's.

SECTION 4

METHANOL-FUELED AUTOMOBILES AND LIGHT-DUTY TRUCKS

METHANOL-FUELED AUTOMOBILES AND TRUCKS

° ABOUT 1,000 AUTOMOBILES AND LIGHT-DUTY TRUCKS IN THE UNITED STATES HAVE BEEN MODIFIED OR SPECIFICALLY MANUFACTURED TO OPERATE ON METHANOL.

° ADDITIONAL RESEARCH AND DEVELOPMENT COULD PRODUCE METHANOL ENGINES WITH BETTER EFFICIENCY, POWER OUTPUT, AND EXHAUST EMISSIONS THAN GASOLINE ENGINES.

° CHRYSLER, FORD, AND GENERAL MOTORS SAID THAT THE MOST PROMISING ALTERNATIVE PRODUCTION CAR FOR THE UNITED STATES COULD BE A METHANOL AUTOMOBILE, PROVIDED THAT TECHNICAL, REGULATORY, AND MARKETING PROBLEMS ARE RESOLVED.

--PRODUCING METHANOL AUTOMOBILES WOULD REQUIRE SOLVING SOME TECHNICAL PROBLEMS, ESPECIALLY COLD STARTING.

--ESTABLISHING REGULATIONS FOR METHANOL AUTOMOBILE EMISSIONS AND FUEL ECONOMY WOULD RESOLVE UNCERTAINTY.

--MARKETING METHANOL AUTOMOBILES WOULD REQUIRE DEMAND AND FUEL AVAILABILITY.

This section discusses the modifications necessary to use methanol fuel in automobiles and light-duty trucks, fleet operators' experience, and methanol engine research and development. The views of automobile manufacturers on producing methanol-fueled automobiles are also presented.

METHANOL AUTOMOBILES AND TRUCKS

An estimated 1,000 methanol-fueled automobiles and light-duty trucks are operating in the United States. Driving a methanol-fueled automobile is about the same as operating a conventional, gasoline-fueled automobile. Since methanol has less energy per gallon than gasoline, methanol-fueled automobiles get poorer fuel economy in terms of the volume of fuel used, but fuel economy in terms of energy used is comparable or slightly better for methanol-fueled automobiles. Methanol-fueled automobiles and trucks also have better acceleration. As shown in figure 4.1, methanol-fueled automobiles look identical to their gasoline counterparts. Refueling is accomplished in the same manner as gasoline, from the same type of pump, as shown in figure 4.2. These similarities would enable vehicle operators to adapt to methanol-fueled vehicles without being required to learn new driving or refueling techniques.

Figure 4.1: A Methanol-Fueled Automobile

MODIFYING AUTOMOBILES AND TRUCKS TO OPERATE ON METHANOL

° MODIFICATIONS INCLUDE

--REPLACING METHANOL SENSITIVE MATERIAL IN THE FUEL SYSTEM,

--INSTALLING A LARGER, METHANOL COMPATIBLE FUEL TANK,

--INCREASING FUEL FLOW AND CHANGING THE AIR/FUEL RATIO,

--CHANGING IGNITION TIMING AND SPARK PLUGS, AND

--USING A SPECIALLY FORMULATED LUBRICATING OIL.

Figure 4.2: Methanol Fuel Pump

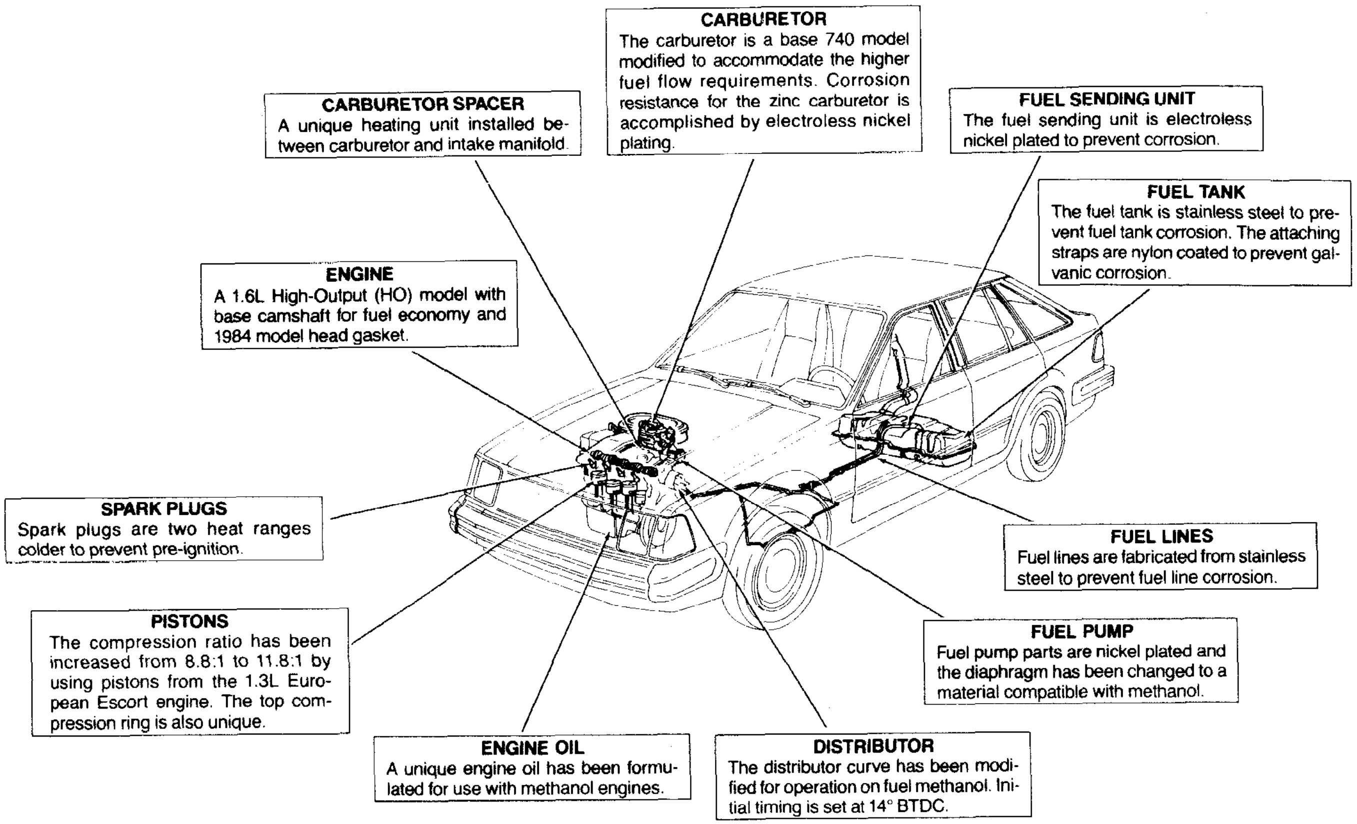
MODIFYING AUTOMOBILES AND TRUCKS TO OPERATE ON METHANOL

Several modifications were made in order to operate automobiles and light-duty trucks on methanol fuel. Many of these changes are shown in figure 4.3, for a Ford Escort. Modifications to light-duty trucks are basically the same as automobile modifications.

Material compatibility

While the materials currently used in automotive fuel systems are gasoline durable, some materials will dissolve or deteriorate in methanol. Among the materials subject to methanol deterioration are (1) terne metal (a mixture of lead and tin) commonly used to coat the inside of fuel tanks, (2) zinc, (3) aluminum, and (4) some elastomers (rubberlike compounds used for gaskets, seals, etc.). These materials were replaced with methanol compatible materials at those places coming in contact with methanol.

Figure 4.3: Modifications Made on a 1983 Ford 1.6L Escort



Source: Ford Motor Company.

Fuel system

Methanol-fueled automobiles and trucks that have been converted from gasoline need larger fuel tanks in order to achieve a driving range similar to gasoline-fueled vehicles because methanol has about one-half the energy content per gallon of gasoline. Existing methanol automobiles require about 1.8 gallons of methanol fuel to travel as far as a gasoline car on 1 gallon of gasoline. In addition, methanol's lower volumetric energy content (see glossary for an explanation of this and other technical terms) compared with gasoline requires an increased rate of fuel flow from the fuel tank to the engine. Methanol-fueled vehicles also require a greater amount of fuel in the air/fuel mixture, which is burned in the cylinders, than gasoline-fueled engines. These changes are usually accomplished by adjusting the carburetor or fuel injection system. A larger capacity fuel pump may also be required.

Spark plugs and ignition timing

Methanol has a hot surface ignition temperature that is 150°F cooler than gasoline. As a result, liquid methanol hitting a hot surface ignites easier than liquid gasoline. Since the spark plug electrodes can be the hottest part of the engine, methanol droplets hitting a hot spark plug can ignite before the spark plug fires, causing premature combustion and engine knock. Methanol engines use spark plugs with better heat transfer to mitigate this problem. Methanol-fueled vehicles also require modifications to the spark plug ignition timing compared with gasoline-fueled vehicles. The ignition timing determines the piston's position in a cylinder when the spark plug ignites the air/fuel mixture.

Lubricants

Special lubricating oil formulations are being used to help reduce cylinder corrosion and wear in methanol engines and to make the oil more compatible with methanol fuel. Cylinder wear in some cases has been partially attributed to the greater acidity of methanol combustion products compared with those of gasoline. To neutralize this acidity, the lubricating oil used in methanol engines is more alkaline than conventional lubricating oil. Research indicates that in some cases the greater acidity of methanol combustion products might be partly attributed to contaminated fuel.

FLEET OPERATIONS

- CALIFORNIA HAS ABOUT 550 METHANOL-FUELED AUTOMOBILES.

- CALIFORNIA ESTABLISHED 18 STATE-SPONSORED PUBLIC METHANOL REFUELING FACILITIES AND IS IN THE PROCESS OF ADDING 11 MORE.

- CALIFORNIA'S INTEREST IN METHANOL-FUELED VEHICLES STEMS FROM CONCERN OVER FUEL SUPPLY SECURITY AND THE ENVIRONMENT.

- THE BANK OF AMERICA IS OPERATING ABOUT 275 METHANOL-FUELED AUTOMOBILES AND TRUCKS AND MAINTAINS SIX PRIVATE METHANOL REFUELING FACILITIES.

- THE BANK'S INTEREST IN METHANOL-FUELED AUTOMOBILES STEMS FROM ITS CONCERN OVER A SECURE FUEL SUPPLY.

FLEET OPERATIONS

The California Energy Commission (CEC) and the Bank of America have the most operational experience with methanol automobiles and trucks in the United States. CEC is supervising an experimental program with about 550 factory built methanol-fueled automobiles. Bank of America uses about 275 gasoline automobiles and trucks retrofitted to operate on methanol as part of its regular fleet operations.

California

California's methanol program started with four Ford Pintos converted to operate on methanol in 1980. California studied various alternative fuels and focused on methanol because it is clean burning, potentially abundant, and similar to existing fuels. In 1981 testing was expanded to include 19 factory produced methanol Volkswagens and 40 Ford Escorts modified to operate on methanol. In 1983 California purchased 507 factory-produced methanol Ford Escorts. To fuel its methanol automobiles, California established a methanol refueling system. By 1984, 18 methanol refueling facilities were operating in California. As of May 1986, only 16 of the state's methanol refueling facilities were operating because some of the contracts had lapsed. Contracts for an additional 11 new facilities have been signed, and some could be operating by the end of 1986.

While some problems occurred with the methanol automobiles and fuel quality, most of the 1983 vehicles continue to operate. Collectively, these vehicles have accumulated over 12 million miles. Durability was a problem with the Ford Pinto conversions; however, the Escorts have fared better. One of the 1981 Escorts was retired after 122,000 miles and returned to Ford for analysis. The engine showed minimal wear and no carbon build up. CEC said that methanol engines could be more durable than gasoline engines due to methanol's clean burning attributes. CEC also said that it is important to remember that current durability experience is based on gasoline engines modified to operate on methanol, not engines completely designed for methanol. Further, according to CEC, California will retain its interest in the use of methanol as a substitute for gasoline primarily for environmental reasons despite the drop in oil prices.

Bank of America

The Bank of America began evaluating alternatives to gasoline in 1979, out of concern over fuel shortages. The Bank operates a fleet of about 2,350 automobiles and light-duty trucks throughout California. Originally, the Bank converted 25 automobiles to methanol. By the end of 1985, 275 vehicles, or 12 percent of its fleet, were operating on methanol. The Bank's vehicles are conventional automobiles and trucks retrofitted to accommodate methanol fuel. Some of the conversions were performed by Bank

mechanics and involved a variety of modifications, including replacing carburetors and fuel tanks and substituting methanol-tolerant materials and components. The Bank maintains six private refueling facilities and has access to the state-operated facilities.

Bank of America considers its methanol vehicles to be successful. Through late 1985, the Bank's methanol vehicles have accumulated over 15 million miles. Bank officials told us that their methanol fleet performs satisfactorily, meets California's tough emission control standards, and is cost effective. Bank officials are considering expanding the methanol fleet when market conditions are right. However, Bank officials also told us that they would prefer purchasing methanol automobiles produced at the factory rather than retrofitting more gasoline automobiles. The officials believe that automobile manufacturers would be able to apply engineering and technological expertise that would lead to methanol vehicles that are superior to retrofits.

ENGINE RESEARCH AND DEVELOPMENT

- METHANOL'S CHEMICAL PROPERTIES OFFER OPPORTUNITIES TO IMPROVE ENGINE EFFICIENCY, POWER, AND EXHAUST EMISSIONS COMPARED WITH GASOLINE-POWERED ENGINES.

- ENGINE RESEARCH AND DEVELOPMENT AREAS INCLUDE

  --HIGHER COMPRESSION COMBUSTION,

  --FUEL PREPARATION FOR COMBUSTION, AND

  --SPARK PLUG AND COMBUSTION CHAMBER MODIFICATIONS.

ENGINE RESEARCH AND DEVELOPMENT

Automobile manufacturers and engine experts told us that with additional research and development, methanol engines could outperform gasoline engines in terms of thermal efficiency and power output, with improved exhaust emissions, and equivalent cruising range and production cost. Some of these improvements are already being tested, while others are less developed. The Director, Emission Control Technology Division, EPA, informed us that the use of pure methanol rather than M85 could enhance vehicle performance and environmental benefits, facilitate fuel regulation and engine design, and make some of these improvements more feasible.

Higher pressure combustion

Methanol's octane rating, which is higher than gasoline's octane rating, allows for higher pressure combustion and improved fuel efficiency.[3] Some experts believe that increasing the compression ratio without sacrificing engine durability and reliability would require strengthening engine components subject to additional stress. To gain maximum fuel efficiency from increased compression ratios, it might be necessary to modify the drive train to take advantage of the higher power output.[4]

Fuel preparation for combustion

Fuel must be prepared for combustion by changing it from a liquid to a gas as it is mixed with air. Liquid fuel is first atomized (broken into fine droplets) by either the carburetor, throttle body fuel injector, or multiport fuel injectors, depending on the type of equipment in the car. Once in the cylinder, the fuel is vaporized by the heat of compression (changed from atomized droplets to a gas) prior to combustion. The smaller the atomized droplets, the more easily and completely the fuel will vaporize.

Methanol preparation

Improved fuel preparation for methanol engines could improve cold starting and fuel efficiency and reduce exhaust emissions. Early methanol automobiles used carburetors. Newer methanol vehicles use throttle body or multiport fuel injection, which controls the fuel more effectively and distributes it more uniformly. Multiport fuel injection offers the most precise fuel atomization; however, improvements that could further reduce fuel

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[3]Octane rating is a measure of a fuel's resistance to premature ignition under compression which can lead to "knock" and power loss. Therefore, octane rating is a measure of a fuel's knock resistance. The higher the rating, the greater the resistance.

[4]Drive train is a general term that includes the parts after the engine that transfer power to the wheels.

droplet size are possible. Other techniques being tested use small electric heaters to heat the atomized fuel to enhance vaporization during cold starting or heat from the engine coolant and exhaust after the engine has warmed up.

Lean burn

Lean burn is a technique that could improve fuel efficiency. Most conventional engines are designed to burn a mixture of air and fuel with precisely enough air for complete fuel combustion. Lean burn increases the proportion of air present in the combustion chamber relative to the fuel. Since methanol has a leaner flammability limit than gasoline, it can be ignited at a more fuel-lean mixture without misfire.

Dissociation

Breaking some of the methanol down into its component parts prior to combustion could provide a way to improve methanol engine starting in cold weather. This process, called dissociation, is the chemical breakdown of methanol into carbon monoxide and hydrogen prior to combustion. Various methods of methanol dissociation are being evaluated. Dissociation also has the potential to improve fuel economy and reduce exhaust emissions.

Spark plug and combustion chamber

Existing methanol engines use spark plugs similar in design to gasoline engines. Developing a spark plug for methanol fuel, together with a redesigned combustion chamber, could improve fuel economy, reduce exhaust emissions, and improve methanol engine starting in cold weather.

AUTOMOBILE MANUFACTURERS' VIEWS ON METHANOL AUTOMOBILES

- FORD, GENERAL MOTORS, AND CHRYSLER ARE EXPERIMENTING WITH METHANOL-FUELED AUTOMOBILES.

- AUTOMOBILE MANUFACTURERS SAID THAT THE PRODUCTION OF METHANOL AUTOMOBILES COULD BE POSSIBLE WHEN

  --SOME TECHNICAL PROBLEMS HAVE BEEN SOLVED,

  --FEDERAL METHANOL REGULATIONS HAVE BEEN ADOPTED, AND

  --A MARKET FOR METHANOL AUTOMOBILES DEVELOPS AND A REFUELING INFRASTRUCTURE EXISTS.

MANUFACTURERS' VIEWS ON METHANOL-FUELED AUTOMOBILES

Ford, General Motors, and Chrysler are experimenting with methanol-fueled automobiles. In congressional testimony, representatives of the automobile manufacturers said that from a technology aspect, methanol automobiles could be produced in quantity in a few years after some technical problems are solved. Some of the representatives said, however, that there is a need to incorporate methanol vehicles under current fuel economy and emissions regulation and develop a methanol automobile market and refueling infrastructure.

In testimony before the Subcommittee on Fossil and Synthetic Fuels, House Committee on Energy and Commerce, in November 1985, representatives from Chrysler, Ford, and General Motors said that methanol is the most promising alternative vehicle fuel for the United States.[5] Of these manufacturers, Ford has the most experience with methanol-fueled automobiles. Ford produced about 630 methanol automobiles, 582 of which were produced on an assembly line. General Motors produced about 20 methanol automobiles for its own testing and evaluation. Chrysler's representative said that Chrysler built a number of methanol-fueled vehicles for research and development purposes and plans to continue these efforts.

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[5]The Director of Power Train Engineering, testified for Chrysler; the Director, Automotive Emissions and Fuel Economy Office, testified for Ford; and the Executive Director, Environmental Activities Staff, testified for General Motors.

UNRESOLVED TECHNICAL ISSUES

- ° COLD WEATHER STARTING IS THE PRIME UNRESOLVED METHANOL-FUELED AUTOMOBILE PROBLEM.
- ° THE CAUSES OF EXCESSIVE ENGINE WEAR HAVE BEEN IDENTIFIED AND POSSIBLE SOLUTIONS ARE BEING TESTED.
- ° CORROSION CAUSED BY WATER PRODUCED DURING COMBUSTION REQUIRES MEASURES TO PREVENT WATER ACCUMULATION IN THE ENGINE AND EXHAUST SYSTEM.
- ° SOME UNCERTAINTY PERSISTS ABOUT METHANOL COMPATIBLE MATERIALS.

UNRESOLVED TECHNICAL ISSUES

Automobile manufacturer representatives said that unresolved technical issues, primarily cold weather starting and driveability, have to be resolved before they would produce methanol automobiles on the assembly line in quantity. Ford testified before the Senate Committee on Commerce, Science, and Transportation in July 1985 and the Subcommittee on Fossil and Synthetic Fuels, House Committee on Energy and Commerce, in November 1985,[6] that these technical problems are a matter of engineering refinement and could be solved in the next few years.

Cold starting

At temperatures below about 50°F, methanol does not produce enough vapor to form flammable mixtures in the combustion chamber. This can cause difficulty starting the engine. A number of methods have been used to improve cold starting, including fuel additives, improved fuel vaporization and combustion techniques, and auxiliary fuel systems. For example, GM's methanol cars use an auxiliary propane fuel system. However, auxiliary fuel systems are considered too cumbersome for production use. Ford adds gasoline to the methanol and carburetor heaters to improve cold starting. While these methods have provided acceptable starting below 50°F, they will not provide reliable starting down to the industry target level of -20°F. The manufacturers said that further development is needed to achieve customer satisfaction with performance in all climates.

Engine lubrication and wear

In some cases, engine wear has been more severe with methanol than gasoline. Research indicates that much of this excessive wear occurs during cold engine operation and on short trips when the engine does not operate long enough to warm up. In addition, some components of conventional multigrade engine oil are incompatible with methanol which causes the oil to become less effective. In response to these problems, alternative materials are being used for engine components that have shown excessive wear. Several oil formulations have been developed specifically for methanol engines. These are being tested, and experts believe long-term observation is needed to assure their efficacy.

Corrosion

Methanol-fueled vehicles can also experience accelerated exhaust system corrosion because methanol combustion produces twice as much water as gasoline. When the car is turned off,

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[6]The Vice President of Ford Motor Company, testified in July, and the Director, Automotive Emissions and Fuel Economy Office, Ford Motor Company, testified in November. Ford's Principal Research Engineer, Engine Research Department, appeared at both hearings.

water condenses and collects in low spots. Water accumulation can cause corrosion in the exhaust system. GM is considering the use of water absorbing materials in the exhaust system to help reduce water accumulation.

Materials compatibility

Uncertainty persists about methanol compatible materials. Methanol compatible materials can withstand exposure to methanol without deteriorating as a result of a chemical reaction between methanol and the material. For example, an elastomer called fluorosilicone has been cited by some sources as methanol compatible; however, GM has documented problems with it in some applications. Elastomers are rubber-like compounds used for gaskets, seals, and other applications requiring flexible fittings. Research by automotive companies indicates that small changes in the chemical composition of materials can make a large difference in its compatibility with methanol.

Another problem occurs when gasoline is mixed with methanol. Fifteen percent gasoline is used in methanol fuel or M85 as a cold weather starting aid and to address safety issues. Since methanol and gasoline are compatible with different types of materials, finding materials compatible with both methanol and gasoline is more difficult than finding a material compatible with either one. Experts said that further testing is necessary to assure adequate materials performance for methanol vehicles.

REGULATORY UNCERTAINTIES

- FEDERAL REGULATION OF METHANOL-FUELED AUTOMOBILES IS UNCERTAIN BECAUSE

  --FEDERAL EMISSION CERTIFICATION STANDARDS COVERING METHANOL-FUELED AUTOMOBILES HAVE NOT BEEN FINALIZED AND

  --IT IS NOT CLEAR WHETHER OR HOW METHANOL-FUELED AUTOMOBILES WILL BE INCLUDED IN THE CORPORATE AVERAGE FUEL ECONOMY STANDARDS.

METHANOL-FUELED AUTOMOBILE MARKET

- BEFORE STARTING METHANOL-FUELED AUTOMOBILE PRODUCTION, MANUFACTURERS SAID THEY NEED SOME ASSURANCE THAT

  --A DEMAND EXISTS FOR METHANOL-FUELED AUTOMOBILES AND

  --A REFUELING INFRASTRUCTURE EXISTS THAT CAN PROVIDE FUEL AT COMPETITIVE PRICES.

REGULATORY UNCERTAINTIES

Several uncertainties persist concerning federal regulation of methanol-fueled automobiles. Emissions standards under the Clean Air Act for methanol-fueled vehicles have not been promulgated. However, automobile manufacturers expect that methanol-fueled vehicles will be required to meet federal certification standards to be established by EPA. EPA is currently preparing proposed standards that are expected to be ready for public comment during 1986.

Because methanol is not currently defined as a fuel under the Motor Vehicle Information and Cost Savings Act or DOT regulation, it is not covered by corporate average fuel economy standards. It is not clear whether or how methanol vehicles would be incorporated into the act. The legislation gives the Secretary of Transportation the authority to include new fuels in the act. If methanol is incorporated into the act, EPA is required to determine the quantity of methanol that is equivalent to 1 gallon of gasoline for fuel economy calculations.

METHANOL-FUELED AUTOMOBILE MARKET

Automobile manufacturers said that they would not produce methanol-powered automobiles unless a sufficient number can be sold to make it profitable. Chrysler said that as a rule, it would not put a unique model into production unless sales of at least 5,000 cars per year can be achieved on a sustained basis.

The lack of methanol fuel availability at the retail level and comparatively low gasoline prices are disincentives for producing methanol vehicles. GM said that a transition to methanol could begin when automobiles can operate on methanol as cheaply as gasoline. GM estimates that gasoline prices would have to exceed $1.40-$1.50 per gallon for a significant period of time to provide investors with the necessary confidence to construct the required methanol processing and distribution facilities. GM also said that there would be little incentive to buy methanol-fueled vehicles until the cost of operating methanol and gasoline vehicles is equivalent on a cost-per-mile-of-travel basis.

SECTION 5

FLEXIBLE FUEL VEHICLES

FLEXIBLE FUEL VEHICLES

- ° FORD HAS DEVELOPED AN AUTOMOBILE CALLED A FLEXIBLE FUEL VEHICLE (FFV) THAT CAN USE GASOLINE, METHANOL, OR ANY COMBINATION OF THE TWO.

- ° FFV TESTS HAVE SHOWN FAVORABLE RESULTS; HOWEVER, FURTHER REFINEMENT AND TESTING IS NEEDED.

- ° FORD REPRESENTATIVES SAID THAT FFV'S COULD BE PRODUCED IN THE EARLY 1990'S PROVIDED SOME TECHNICAL PROBLEMS ARE RESOLVED.

- ° FFV'S COULD BE AN ALTERNATIVE AUTOMOBILE TO BRIDGE THE GAP BETWEEN GASOLINE AND METHANOL AUTOMOBILES.

This section discusses the development of the flexible fuel vehicle, an automobile that can operate on gasoline, methanol, or any combination of the two. The potential of FFVs to provide a bridge between methanol and gasoline automobiles makes them potentially useful as transition vehicles.

FFV OPERATION

The FFV relies on innovations in electronic sensors and on-board computers to automatically determine the relative proportions of methanol and gasoline in the fuel mixture to adjust engine operations. Unlike previous efforts at dual or multifuel vehicles that required expensive multiple fuel systems and manual control, the FFV uses a single fuel system that automatically adjusts the engine to variable methanol/gasoline mixtures.

The primary component of Ford's FFV is an optical fuel sensor linked to the on-board electronic engine control system now common on new cars. Fuel on the way to the engine passes through the optical sensor. Inside the sensor, a beam of light passes through the fuel. The physical-chemical differences between methanol and gasoline affect this beam of light in proportion to their respective content in a way that can be measured and analyzed by the engine control computer. On the basis of this information, the computer is able to determine the relative amounts of methanol and gasoline in the fuel. With this, and other data from sensors that measure the amount of air flowing into the engine and the amount of oxygen coming out of the exhaust, the computer's preprogrammed instructions provide the proper fuel flow and spark timing for the particular fuel mixture.

FFV PERFORMANCE

Ford reported that, overall, FFVs operating on methanol or gasoline gave similar favorable results and that the driveability, fuel efficiency, and exhaust emissions have also been favorable. Operating on methanol results in 7 percent higher power without any compression ratio increase.

Ford said, however, that technical problems still exist and additional testing is required before FFVs are ready for production. This includes

- --reducing the electronic sensor's sensitivity to temperature changes and errors induced by some gasoline components;
- --verifying materials compatibility with methanol, gasoline, and the full spectrum of fuel in between;
- --verifying engine oil compatibility with the full spectrum of fuel;

--conducting more testing under various climates and altitudes;

--making long-term durability tests; and

--developing a cold start system.

In order to provide enhanced performance or fuel economy, experts said that FFVs could eventually be designed with higher compression engines that require either methanol or premium lead-free gasoline. Higher compression engines require higher octane fuel (methanol has a research octane rating of about 110, while premium lead-free is about 97-98). Premium's higher price could also increase the likelihood that methanol will be chosen when available.

FFV'S POTENTIAL

In testimony before both House and Senate Committees in June, July, and November 1985, Ford representatives said that about 4 years would be required to resolve the technical problems and fully develop the FFV for sale to the public. Ford estimated that it would cost about $200 more per car to produce an FFV than a gasoline automobile at the 100,000 vehicle per year level.

The FFV could become an alternative automobile to bridge the gap between methanol and gasoline automobiles while awaiting increases in the supply and availability of methanol fuel to the public. The FFV's ability to operate on either gasoline or methanol could increase the demand for methanol fuel. Some experts view the FFV as a transition vehicle that would allow a gradual expansion of demand for methanol fuel.

SECTION 6

METHANOL-FUELED BUSES

METHANOL-FUELED BUSES

° HEAVY-DUTY METHANOL ENGINES ARE BEING EVALUATED AS A SUBSTITUTE FOR DIESEL ENGINES IN URBAN TRANSIT BUSES.

° HEAVY-DUTY ENGINE MANUFACTURERS IN THE UNITED STATES AND ABROAD ARE DEVELOPING METHANOL-FUELED BUS ENGINES.

° TWO METHANOL-FUELED BUSES IN CALIFORNIA ARE OPERATING SATISFACTORILY BUT NEED FURTHER DEVELOPMENT.

° FLORIDA IS DEVELOPING A RETROFIT PROCEDURE TO CONVERT EXISTING DIESEL BUSES TO METHANOL.

° SEVERAL TRANSIT AUTHORITIES ARE CONSIDERING ACQUIRING METHANOL-FUELED BUSES.

° THE URBAN MASS TRANSIT ADMINISTRATION IS FORMULATING A PROGRAM PLAN FOR METHANOL-FUELED BUS DEVELOPMENT.

This section discusses the development of methanol-fueled buses in the United States. Several manufacturers are developing methanol bus engines as a potentially less polluting alternative to diesel engines. Research to date has emphasized the use of methanol engines in urban transit buses. The section also discusses the Urban Mass Transportation Administration's role in methanol bus development.

CALIFORNIA METHANOL-FUELED BUSES

The first U.S. demonstration of methanol-fueled transit bus technology started in California in 1983. Detroit Diesel Allison (DDA), a subsidiary of GM, and Maschinenfabrik Augsburg-Nurnberg (MAN), a West German bus and truck company, are participating in this demonstration. Each company provided the Golden Gate Transit District in San Rafael, California, a methanol version of its bus. MAN also provided a diesel bus and Golden Gate Transit district provided a diesel GM bus to allow performance and fuel economy comparisons between methanol and diesel. The GM/DDA bus, called Methanol One, is shown in figure 6.1. The MAN bus, called Methanol Two, is shown in figure 6.2.

Modifications for methanol operation

The modifications necessary to operate these buses on methanol are similar to the automobile modifications. Materials in the fuel, engine, and exhaust systems that are susceptible to methanol deterioration were replaced with methanol tolerant materials. The on-board fuel storage capacity was increased to compensate for methanol's lower volumetric energy content. Engine operating parameters and control systems were also changed to accommodate methanol fuel. Electronic engine and air control systems were added to allow the DDA engine to compression ignite methanol. Glow plugs were added to the cylinders of the DDA engine to assist ignition during low engine speeds and cold starting. The MAN bus uses spark plugs to ignite the fuel in the cylinders and added a catalytic converter to reduce exhaust emissions.

A summary of the buses' characteristics is shown in table 6.1. Both methanol buses use 100 percent pure methanol with no additives.

Figure 6.1: GM/DDA Methanol-Fueled Bus
Methanol One

Figure 6.2: MAN Methanol-Fueled Bus
Methanol Two

Table 6.1: Bus Coach and Engine Specifications

Vehicle	GM Diesel	GM Methanol one	MAN Diesel	MAN Methanol two
Overall length, ft.	40		38	
Overall width, in.	102		97.6	
Model	RTS II Series 04		SU 240	
Passengers	43		49	
Curb wt. lb	27,300	29,240	24,360	24,760
Fuel tank capacity, gal	125	250	66	132
Engine				
Model	6-V-92TA	6V-92TA Methanol	D 2566MUH	D 2566FMUH
Type	Two-Stroke		Four-stroke	
Configuration	Transverse V6		Horizontal in-line 6-cylinder	
Compression ratio	17:1	19:1	18:1	
Displacement cu. in.	552		696	
Rated power, hp	277		200	
Rated speed, rpm	2,100		2,200	
Ignition system	Compression ignition		Compression ignition	Spark ignition
Starting aid	None	Glow plugs	None	None

Source: Transit bus operation with methanol fuel, SAE 850216.

PERFORMANCE RESULTS

- DESPITE SOME INITIAL PROBLEMS, BOTH METHANOL-FUELED BUSES ARE OPERATING SATISFACTORILY.

- BOTH BUSES REMAIN IN SERVICE, ACCRUING ABOUT 200 MILES PER DAY WITH SOME OCCASIONAL PROBLEMS.

- BOTH BUSES' PERFORMANCE ESSENTIALLY MATCHES THEIR DIESEL COUNTERPARTS. HOWEVER, METHANOL ONE IS OPERATING LESS EFFICIENTLY THAN THE DIESEL BUS. METHANOL TWO IS OPERATING AT ABOUT EQUAL EFFICIENCY TO ITS DIESEL COUNTERPART.

PERFORMANCE RESULTS

The Golden Gate Transit District is collecting data on the buses' operating cost, fuel and oil consumption, emissions, maintenance, driveability, durability, and consumer and driver reaction. This information is being used to further refine the buses.

Continued operation of these buses would provide data on long-term durability and reliability of methanol transit buses. This data is especially important to transit operators because the average life of a transit bus is from 400,000 to 500,000 miles. Diesel engines last between 150,000 to 250,000 miles.

At the end of May 1986, Methanol One had been driven 38,000 miles and is continuing to accrue about 200 miles per day. Initially, the bus experienced operational problems, but changes were made to the fuel and air control systems, and the bus has been operating satisfactorily with only occasional problems. Methanol One's performance in terms of acceleration essentially matches that of its diesel counterpart. Fuel economy, however, is considered inadequate. Methanol One is getting about 1.4 miles per gallon (mpg) on its usual route.[1] In comparison, the diesel version is getting about 4.0 mpg on the same route. This comparison indicates that Methanol One is currently operating about 20 percent less efficiently than the diesel bus. If the buses were operating at equal efficiency, Methanol One's mileage would be about 1.7 mpg. Further research on the engine technology used in Methanol One is expected to improve fuel economy.

Methanol Two had accumulated 49,000 miles at the end of May 1986 and is continuing to accrue about 200 miles per day. Its acceleration essentially matches its diesel counterpart. Unlike Methanol One, Methanol Two's fuel economy matches its diesel counterpart on an energy-equivalent basis. The diesel tested at 5.56 mpg, and Methanol Two achieved about 2.38 mpg methanol (or 5.47 mpg diesel equivalent).[2]

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[1]This is actual methanol fuel consumption. Since 1 gallon of diesel contains the same amount of energy as 2.3 gallons of methanol, multiply the methanol mpg x 2.3, to compare methanol and diesel mpg on an energy-equivalent basis. Thus, 1.4 methanol mpg x 2.3 = 3.22 diesel equivalent mpg.

[2]While these numbers form a valid basis for comparison between the diesel and methanol powered version of the MAN bus, they cannot be compared on an equal basis with the fuel economy of the GM bus. In order to compare the fuel economy of the GM and MAN buses, it would be necessary to take into account the significant equipment differences between the vehicles, such as the use of an auxiliary power source for the air conditioning on the MAN bus and the 3,800 pound weight disadvantage of Methanol One.

TECHNICAL STATUS

- TESTING HAS SHOWN THAT BOTH BUSES NEED FURTHER DEVELOPMENT.

- METHANOL ONE HAS A FIRST-OF-A-KIND EXPERIMENTAL ENGINE THAT REQUIRES FURTHER DEVELOPMENT TO IMPROVE EMISSION CONTROL AND FUEL ECONOMY.

- METHANOL TWO IS AT A MORE ADVANCED STAGE OF DEVELOPMENT, BUT THERE IS A NEED TO FURTHER REFINE ENGINE OPERATIONS AND TEST ENGINES WITH MORE HORSEPOWER.

- RELIABILITY TESTING IS NEEDED TO ESTABLISH THE LONG-TERM DURABILITY OF BOTH BUSES.

TECHNICAL STATUS

Methanol One is a first-of-a-kind experimental engine that needs further development. It is basically a diesel, modified to operate on methanol, and many refinements are needed. For example:

--Emissions reductions are needed that will probably require fundamental engine design work and the addition of a catalytic exhaust emission control system to reduce carbon monoxide, formaldehyde, and unburned methanol emissions.

--Fuel economy improvement is needed that will require changes in the combustion chamber design, fuel injector spray pattern, and the control of fuel and combustion air.

--Reliability testing is needed to establish long-term engine durability.

MAN has been experimenting with methanol-fueled buses for about 15 years. During that time, it has conducted demonstrations in Germany and New Zealand. In California, Methanol Two has performed quite well, displaying excellent driveability and low exhaust emissions. On an energy-equivalent basis, the MAN bus achieved the same fuel economy as its diesel counterpart. Further development is planned and will include technical refinements of engine operation, durability testing, and testing more powerful versions of the methanol engine.

Both the DDA and MAN engines are discussed in more detail in appendix III.

FLORIDA METHANOL RETROFIT PROGRAM

° FLORIDA, WITH FINANCIAL ASSISTANCE FROM THE URBAN MASS TRANSPORATION ADMINISTRATION, DEVELOPED A RETROFIT PROCEDURE FOR CONVERTING BUSES DURING BUS REHABILITATION TO OPERATE ON METHANOL.

° THE RETROFIT PROCEDURE IS DESIGNED FOR ENGINES THAT ARE USED IN ABOUT 90 PERCENT OF THE TRANSIT BUSES IN THE UNITED STATES.

° THE RETROFIT INCLUDES MODIFYING THE ENGINE, FUEL, EXHAUST, AND ELECTRICAL SYSTEMS.

° FLORIDA CONVERTED THREE BUSES TO OPERATE ON METHANOL FUEL AND PLACED THEM IN SERVICE IN JACKSONVILLE, FLORIDA.

FLORIDA METHANOL BUS RETROFIT PROGRAM

The Florida methanol bus retrofit program involves converting transit bus engines from diesel to methanol fuel during bus rehabilitation. Many buses are rehabilitated after 10 to 12 years to extend their service life. During rehabilitation, parts subject to wear are replaced and the engine is rebuilt. Because the engine is rebuilt during rehabilitation, Florida said that this is a good opportunity to convert buses to methanol. Florida's Department of Transportation is developing a retrofit bus procedure that could be applicable to engines that are used in about 90 percent of the transit buses currently operating in the United States. The technology is similar to that being used on the GM/DDA bus in San Francisco, California.

The Urban Mass Transportation Administration (UMTA) provided funding for Florida's retrofit program in order to determine the feasibility of the retrofit conversions. Three buses and a fourth engine were converted to methanol fuel. The major modifications include:

--Installing larger fuel tanks, using methanol tolerant materials in the fuel system, and installing flame arresters in the fill tube and vent.

--Recalibrating the engine for methanol fuel, increasing fuel flow, and adding glow plugs to assist starting.

--Adding a catalytic converter to the exhaust system to reduce carbon monoxide and formaldehyde emissions.

--Modifying the electrical system to provide power for engine glow plugs and an electronic engine control system.

The estimated cost of future conversions is $15,000 to $20,000 per bus. This estimate, however, is based on converting the first three buses and includes some engineering and overhead costs. Florida Department of Transportation officials estimated that the cost could be halved by economies of scale when more buses (50 to 100) are converted. These officials indicated that ultimately, conversion from diesel to methanol fuel would add about 10 percent to the cost of bus rehabilitation.

Program status

As of May 1986, four engines have been converted to methanol. Three bus coaches retrofitted with methanol bus engines have completed testing on a test track and entered service in Jacksonville, Florida, in May 1986. The fourth diesel engine converted to operate on methanol is being used for laboratory testing. Bench tests of the converted engines indicate similar performance for the methanol and diesel engines. Startability has been adequate at the tested ambient temperature of 65°F. Early

OTHER TRANSIT AUTHORITIES' INTERESTED IN METHANOL BUSES

° TRANSIT AUTHORITIES IN RIVERSIDE AND LOS ANGELES, CALIFORNIA; SEATTLE, WASHINGTON; AND NEW YORK, NEW YORK, WILL BE ACQUIRING METHANOL-FUELED TRANSIT BUSES.

° OTHER TRANSIT AUTHORITIES CONSIDERING METHANOL-FUELED BUSES INCLUDE

- DENVER, COLORADO,
- MADISON, WISCONSIN,
- LOWELL, MASSACHUSETTS, AND
- CHARLESTON, WEST VIRGINIA.

durability analysis indicates a normal wear pattern for the methanol engine. However, fuel consumption tests indicate the methanol conversion is 5 to 15 percent less efficient than the diesel. Experts believe that poor fuel atomization and sub-optimal fuel injector timing cause the efficiency loss, and further development in these areas is expected to bring improvement.

The converted methanol engine as currently developed is optimized for performance rather than emissions. A catalytic converter was added which effectively reduced hydrocarbons and carbon monoxide emissions. However, further work is needed to reduce nitrogen oxide and formaldehyde emissions.

OTHER TRANSIT AUTHORITIES' INTEREST IN METHANOL BUSES

Transit authorities in several cities are in various stages of acquiring or considering methanol-fueled transit buses. For example:

--Riverside, California, has an agreement with GM to test three methanol buses scheduled to start in 1986.

--Los Angeles, California, has received UMTA assistance to obtain 30 methanol buses and is preparing to obtain bids from bus manufacturers.

--Seattle, Washington, is expecting delivery on 10 MAN methanol buses in October 1986 and plans to have the buses in service by February 1987. These buses will be improved, more powerful versions of Methanol Two.

--New York, New York, has formalized an agreement with GM and EPA to obtain a total of 32 methanol buses. Six methanol buses will be provided in 1987, with an additional 26 advanced technology methanol buses to be provided in 1989.

--Denver, Colorado, and Madison, Wisconsin, are considering methanol bus testing. Cold weather and high altitude testing is considered critically important in determining methanol transit viability. Cold weather testing is necessary to determine the extent of cold start and other operational problems. High altitude testing is important because nitrogen oxides formation is altitude dependent.

--Lowell, Massachusetts, has applied for funds to retrofit three to four buses for methanol using the retrofit procedure being developed in Florida. Lowell applied for UMTA funding as the cold weather test site for this technology.

--Charleston, West Virginia, is considering methanol bus testing.

UMTA'S ROLE IN METHANOL-FUELED BUSES

- UMTA IS FORMULATING A PROGRAM PLAN ON METHANOL BUS DEVELOPMENT.

- AS A PRIMARY SOURCE OF FUNDS FOR TRANSIT AUTHORITIES, UMTA COULD PLAY AN IMPORTANT ROLE IN THE FUTURE DEVELOPMENT OF METHANOL BUSES.

- METHANOL BUS DEMONSTRATIONS IN SAN FRANCISCO AND LOS ANGELES, CALIFORNIA, AND JACKSONVILLE, FLORIDA, HAVE RECEIVED UMTA FUNDING. LOWELL, MASSACHUSETTS, AND CHARLESTON, WEST VIRIGINIA, HAVE APPLIED FOR UMTA FUNDS TO TEST METHANOL BUSES.

- DECISIONS ON FUNDING FURTHER METHANOL BUS DEMONSTRATIONS WILL DEPEND ON THE RESULTS OF ONGOING AND PLANNED TESTING.

UMTA ROLE IN METHANOL BUSES

UMTA is a primary source of funds for transit companies. The Urban Mass Transportation Act of 1964, as amended, contains formula-based programs for both capital and operating assistance for bus transit systems. UMTA provides up to 80 percent of the funds used for capital purchases and up to 50 percent of the operating assistance required by transit systems. UMTA also administers a discretionary capital grants program that can provide up to 75 percent of the funds for acquiring or improving capital equipment and facilities. This discretionary program is funded by the Mass Transit Account of the Highway Trust fund, which receives one cent per gallon of the federal motor fuel excise tax.

Three of the demonstration programs for methanol buses have received UMTA funds, and two more localities have applied. UMTA is formulating a methanol bus program plan that could include

- --testing a statistically significant sample of methanol-fueled buses for evaluation,
- --preparing a national environmental impact statement, and
- --preparing a methanol bus training program for transit system employees.

As of May 1986, UMTA had not finalized its methanol bus program plan. UMTA said that decisions on future methanol bus demonstrations will depend on the results of ongoing methanol bus experiments.

SECTION 7

METHANOL VEHICLE EXHAUST EMISSIONS

METHANOL VEHICLE EXHAUST EMISSIONS

° EPA REGULATES GASOLINE AND DIESEL AUTOMOBILE EMISSIONS; HOWEVER, METHANOL AUTOMOBILES ARE NOT COVERED BY THESE REGULATIONS.

° EPA IS EVALUATING METHANOL AUTOMOBILE CERTIFICATION STANDARDS AND TEST PROCEDURES. EPA PLANS TO ISSUE PROPOSED STANDARDS FOR PUBLIC COMMENT IN 1986.

° EPA IS ATTEMPTING TO DETERMINE HOW CERTIFICATION STANDARDS WILL APPLY TO FFV'S.

° IT IS NOT CLEAR TO WHAT EXTENT FORMALDEHYDE EMISSIONS FROM METHANOL AUTOMOBILES AND BUSES WILL BE REGULATED.

° ACCORDING TO EPA, METHANOL AUTOMOBILES AND BUSES HAVE THE POTENTIAL FOR REDUCING AIR POLLUTION IN URBAN AREAS.

° METHANOL BUS ENGINES CAN EMIT FEWER POLLUTANTS THAN DIESEL ENGINES.

This section discusses exhaust emissions from methanol automobiles and buses compared with gasoline and diesel emissions. It also describes the current status of EPA certification and emission standards for methanol vehicles.

AUTOMOBILE EXHAUST EMISSIONS

Gasoline and diesel-fueled automobiles are subject to EPA exhaust emission standards for hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NO_x), and evaporative HC emissions. Permissible levels of these pollutants for vehicles manufactured in 1985 and later are shown in table 7.1.[1]

Table 7.1: 1985 and Later
Passenger Car Emission Standards
(federal test procedure)

Hydrocarbons (exhaust)	0.41 g/mi
Carbon monoxide	3.4 g/mi
Oxides of nitrogen	1.0 g/mi
Particulate (for diesels)	0.4 g/mi
	0.2 g/mi(beginning 1986)
Evaporative emissions	2.0 g/test

Source: EPA.

Methanol automobiles are not subject to EPA emission standards. EPA is evaluating potential methanol vehicle emission certification standards and test procedures and plans to issue proposed standards for public comment during 1986. Certification standards specify the criteria EPA uses to inspect and evaluate exhaust and evaporative emissions from new vehicles in order to determine compliance with the Clean Air Act. EPA plans to utilize existing regulations and standards as much as possible.

Research indicates that methanol automobile exhaust includes higher levels of unburned methanol and formaldehyde than gasoline vehicles. EPA research indicates that unburned methanol emissions may be controlled by improved fuel vaporization or other combustion modifications. Formaldehyde can be controlled by installing oxidizing catalytic converters, although existing converters are not effective when the engine is cold. More

[1]These standards apply to passenger cars sold in all states except California. California exhaust emission standards are more restrictive for NO_x and particulates. HC is based on a nonmethane measurement at a slightly lower level (.39 g/mi) and CO is less restrictive at 7 g/mi.

effective formaldehyde control may require the development of catalysts that either operate at lower temperatures or heat up more quickly than current systems. EPA is also attempting to determine how flexible fuel vehicles, discussed in section 5, would be factored into certification standards. Because these vehicles can use any combination of methanol and gasoline, it is unclear which fuel or blend should be used for certification purposes.

Experts believe that methanol automobiles could be designed to meet NO_x emission standards without using reducing catalysts that require engine operation at stoichiometric air/fuel mixtures.[2] Methanol engines are able to operate on very lean air/fuel mixtures that would improve fuel economy and could potentially reduce NO_x emissions without the reducing catalyst. It might also be possible to eliminate exhaust gas recirculation in the engine and maintain acceptable NO_x control. By eliminating the reduction catalyst and exhaust gas recirculation for NO_x control, GM said that it could reduce the cost of producing methanol automobiles and also improve the long-term durability of the exhaust emission control system.

Gasoline automobiles are an important contributor to the photochemical formation of ozone in urban areas. Methanol automobiles produce fewer HC emissions of the type that contribute to harmful ozone formation. HC emissions from methanol automobiles are comprised primarily of unburned methanol fuel, and to a lesser extent, formaldehyde. While formaldehyde is highly photochemically reactive, methanol has low reactivity. Since unburned methanol makes up most of the HC emissions from methanol-fueled cars, EPA said that methanol automobiles could reduce urban ozone levels. EPA estimates that about one-half of the U.S. population lives in metropolitan areas that are in nonattainment of ambient ozone standards. According to EPA calculations, replacing gasoline-fueled automobiles with methanol-fueled automobiles could reduce the ozone-producing impact of each vehicle by as much as 50 percent. Ford has conducted modeling studies based on data from actual methanol automobile operation which indicate that replacing gasoline with methanol vehicles could reduce average ozone levels in urban areas up to 20 percent.

New York City is considering testing Ford methanol taxis in late 1986 or early 1987 as a means of reducing air pollution, particularly CO. New York City officials said that testing

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[2]Stoichiometric mixtures contain the precise amount of air necessary for complete combustion of a given amount of fuel.

BUS EXHAUST EMISSIONS

- EPA ESTABLISHED REGULATIONS REQUIRING SUBSTANTIAL REDUCTION OF NO_X AND PARTICULATE EMISSIONS FROM NEW URBAN TRANSIT BUSES BY 1991. METHANOL BUSES HAVE A POTENTIAL EXHAUST EMISSION ADVANTAGE OVER DIESEL BUSES.

- TEST RESULTS SHOW THAT METHANOL-FUELED BUSES CAN EMIT LESS PARTICULATE MATTER AND NO_X.

Table 7.2: Estimated Percentage of Total Urban Particulate Levels Caused by Buses

City	Percent of total particulate
Washington, D.C.	50
New York	38
Denver	28

Source: Detroit Diesel Allison.

methanol taxis could quickly provide information on operation in the northeast's climate because New York City taxis rapidly accrue mileage. The first prototype methanol taxi has been built. Emissions tests so far indicate that the emission expectations set by the city have been met.

BUS EXHAUST EMISSIONS

The 1977 amendments to the Clean Air Act require a 75-percent reduction of NO_x and the greatest emission reduction achievable for particulate matter from heavy-duty diesel engines. Regulations were established in 1985 that require substantial reductions of NO_x and particulate emissions from new urban transit buses by 1991.

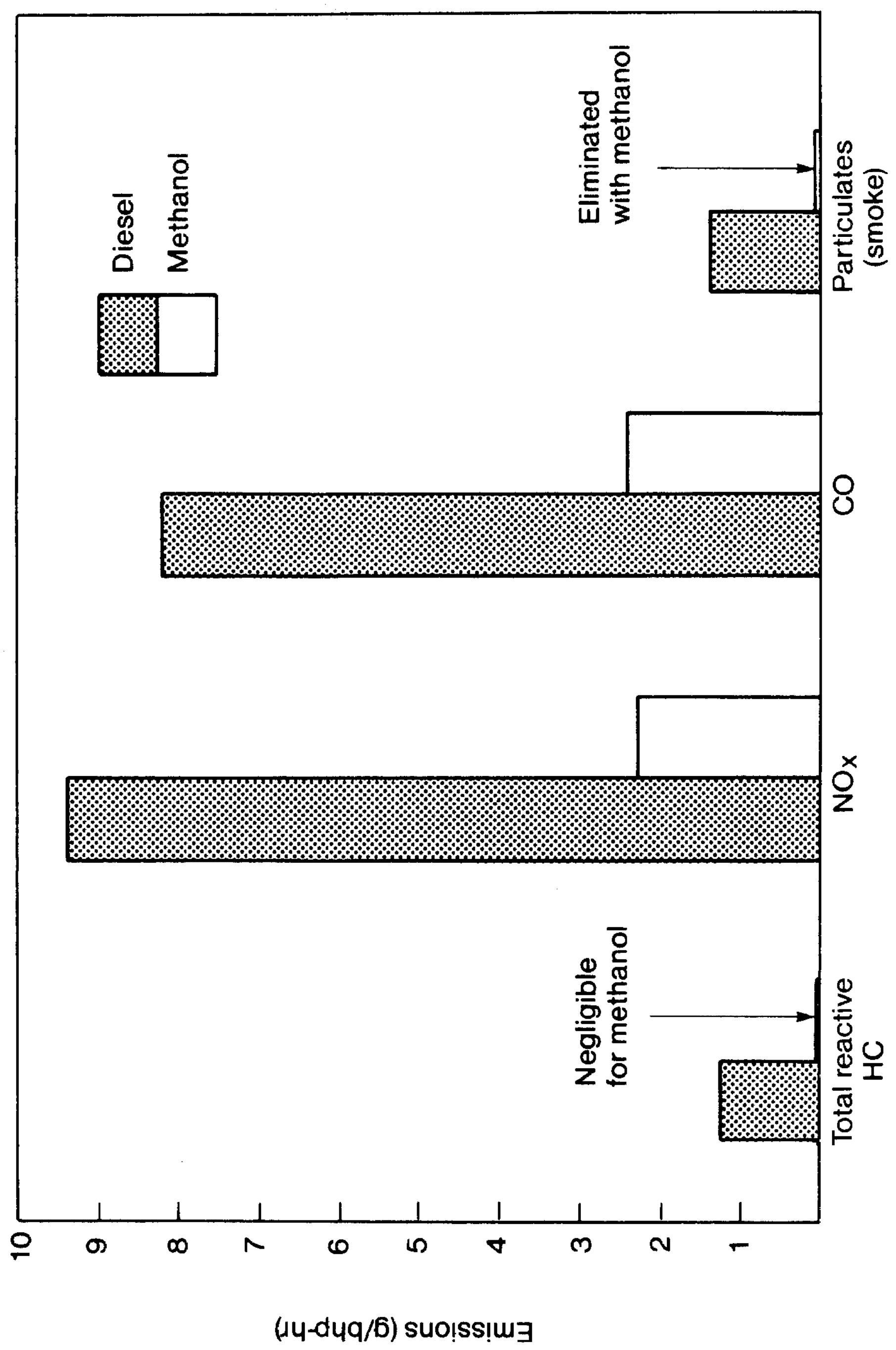
Vehicle emission impact studies show that public exposure to diesel bus emissions is much higher than previously thought. Table 7.2 shows industry estimates of the percentage of particulates contributed by bus operations in several major U.S. cities. EPA believes these emissions have a significant impact on public health and welfare because transit buses typically operate on the most populated roadway corridors, and buses emit pollutants near ground level.

As shown in figure 7.1, methanol bus engines have a potential exhaust emission advantage over diesel engines. Diesels inherently produce high levels of particulate matter, NO_x, as well as visible smoke, sulfur compounds, and a strong odor. Attempts to reduce diesel pollutants by modifying engines and treating exhaust have been technologically difficult.

Initial tests of the DDA engine showed very low particulates and nitrogen oxides emissions. This information, along with data on the MAN engine, is shown in table 7.3 compared to a typical diesel engine. Total organics emissions of the DDA engine appear similar to the diesel engine; however, the nature of the organic emissions, and their ozone producing potential, is significantly different. In addition, methanol combustion releases none of the sulfur oxides and considerably less smoke than diesel combustion.

EPA conducted further testing during the summer of 1985 in order to compare the emissions of methanol and diesel buses. These tests were conducted to determine the effect of actual transit use on the emissions characteristics of diesel and methanol engines. As shown in table 7.4, both methanol engines produce very low particulate levels. Low particulate levels and the absence of sulfur permit the use of catalytic converters which, as shown by the MAN bus data, reduce total organics and CO. However, the GM methanol bus produced high CO and unburned methanol emissions, which is an indication of incomplete combustion and the need for additional engine design work. Adding a catalytic converter, which EPA believes should be mandatory, could also lower these emissions. The GM methanol-fueled bus also turned in the lowest NO_x emission ever reported to EPA for a heavy-duty engine.

Figure 7.1: Potential Emission Advantages With Methanol-Fueled Bus Engines



Source: Acurex.

Table 7.3: Comparison of Diesel and Methanol Bus Engine Emissions Over Various EPA Test Cycles

Pollutant	Typical new diesel bus engine[a]	New MAN methanol bus engine[b]	New GM methanol bus engine[c]
	(g/brake horsepower-hour)		
Particulates	0.57	0.04	0.17
Nitrogen oxides	6.25	6.60	2.20
Carbon monoxide	3.22	0.31	1.31
Total organics	1.61	0.68	1.28
Hydrocarbons	1.51	0.001	-
Methanol	-	0.68	1.13
Aldehydes	0.10	0.001	0.15

[a]Average of three new diesel bus engines tested over the EPA transient engine cycle on No. 1 diesel fuel.

[b]Prototype engine equipped with an oxidation catalytic converter and tested over the EPA transient engine cycle.

[c]Prototype engine without aftertreatment and tested over the 13-mode steady-state engine cycle.

Source: EPA.

Table 7.4: In-Use Diesel and Methanol Bus Emissions

Pollutant	Diesel bus[a]	MAN Methanol bus[b]	GM Methanol bus[c]
	(g/mile)		
Particulates	5.52	0.09	1.09
Nitrogen oxides	26.10	13.60	7.90
Carbon monoxide	51.90	0.65	107.00
Organics	3.88	1.40	120.00
Hydrocarbons	3.35	0.09	1.15
Methanol	0.00	1.16	116.00
Aldehydes	0.53	0.15	2.33

[a]Average of seven in-use diesel buses with 55,000 to 247,000 miles accumulated prior to testing.

[b]Equipped with oxidation catalytic converter.

[c]Not equipped with catalytic converter.

Source: EPA.

As shown in tables 7.3 and 7.4, the MAN engine produced lower levels of particulate, CO, and total organics than the GM engine. The lower particulate level is due to engine operation, while the large reductions in CO and total organics, particularly aldehydes, are due to both engine operation and the use of an oxidative catalytic converter on the MAN engine.

SECTION 8

METHANOL FUEL SAFETY

METHANOL FUEL SAFETY

° EVIDENCE ON THE HEALTH HAZARDS OF METHANOL COMPARED WITH GASOLINE IS INCONCLUSIVE. BOTH FUELS ARE TOXIC AND EACH POSES CERTAIN HEALTH RISKS.

° UNDER CERTAIN CIRCUMSTANCES, METHANOL MAY PRESENT A GREATER FIRE HAZARD IN A CLOSED TANK THAN GASOLINE. IN AN OPEN AREA, METHANOL IS LESS OF A FIRE HAZARD.

° METHANOL SPILLING ON A HOT ENGINE COULD BE MORE HAZARDOUS THAN GASOLINE BECAUSE OF METHANOL'S LOWER SURFACE IGNITION TEMPERATURE.

° PURE METHANOL BURNS WITH A NEARLY INVISIBLE FLAME WHICH CAUSES SOME SAFETY CONCERNS IN CASE OF A FIRE.

This section discusses the state of knowledge regarding the relative safety of methanol as a vehicle fuel compared with gasoline. Topics discussed include health impacts, fire hazard, and flame visibility which are important safety issues.

HEALTH IMPACTS

Information on the potential health effects of methanol fuel use is inconclusive. Methanol fuel use would result in increased exposure to relatively low levels of methanol and its combustion products in the atmosphere. According to published reports on methanol toxicology, most of the available health information on methanol relates to acute industrial exposure and accidental ingestion. Information on the health effects of chronic low level exposure to methanol is lacking.

Table 8.1 shows comparative toxicity ratings for gasoline, methanol, and formaldehyde which is a combustion product of methanol. Since gasoline is a variable mixture of many chemicals, comparative toxicity varies with the chemical composition of the gasoline. As shown in table 8.1, under some circumstances, gasoline can be more toxic than methanol. Gasoline contains chemicals called aromatics. The higher the aromatic content, the more toxic and carcinogenic the gasoline. Since, as shown in table 8.1, formaldehyde appears to be more toxic than gasoline or methanol, minimizing the health risks from methanol fuel use could require effective formaldehyde emission control systems.

Table 8.1: Comparative Toxicity Ratings

	Eye contact	Inhalation	Skin penetration	Skin irritation	Ingestion
Gasoline	(2)	(3)	(3)	(1)	(2)
Methanol	2	2	2	1	1
Formaldehyde	4	3	4	4	3

1 = mild; 5 = extreme toxicity; ( ) = estimated--depends on composition

Source: Handbook of Analytical Toxicology-Chemical Rubber Co.

Because methanol does not have a strong odor, there is some concern over the possibility of being exposed to high levels of methanol without realizing it. Various additives are being evaluated which could give methanol fuel a stronger odor without increasing undesirable vehicle emissions or increasing engine wear.

FIRE HAZARD

The potential for a methanol fire varies according to whether the methanol is in a closed tank or in open air. In a closed tank, under some circumstances, methanol can present a greater fire hazard than gasoline. While vapors above the liquid in a gasoline tank are not flammable at most ambient temperatures, methanol vapors in a fuel tank can be flammable. Ford has shown that the small percentage of gasoline in the methanol fuel being used in automobile testing mitigates this problem by enriching the vapors in a closed tank beyond the flammability limit down to a much lower ambient temperature, more like that of gasoline. Flame arresters can be used in fuel tank fill tubes and vents to prevent an ignition source from entering the vapor space. In the open air, methanol is less of a fire hazard than gasoline partly because methanol has a higher flashpoint than gasoline. In addition methanol fires can be extinguished with water. However, methanol spilling on a hot engine could be more hazardous than gasoline because of methanol's lower surface ignition temperature.

FLAME VISIBILITY

Pure methanol burns with a nearly invisible flame because its combustion produces very few particulates. There is some safety concern about the lack of methanol flame visibility in case of a fire. The gasoline added to methanol to make M85 increases flame visibility and particulate formation. EPA and Ford have evaluated additives that could increase methanol flame visibility; however, many of these could greatly increase engine wear and could also reduce the life of the exhaust emissions catalyst.

GOVERNMENT AND INDUSTRY ORGANIZATIONS GAO CONTACTED

FEDERAL

Department of Defense

Fort Belvoir Research and Development Center, Ft. Belvoir, Va.
Office of the Assistant Secretary of Defense, Logistics and Materials Management
Presidio Army Base, San Francisco, CA.

Department of Energy

Office of Vehicle and Engine Research and Development

Environmental Protection Agency

Emission Control Technology Division - Motor Vehicle Emissions Laboratory, Ann Arbor, MI.

Department of Transportation

Urban Mass Transportation Administration - Office of Energy and Propulsion Systems

STATE

California

California Energy Commission
South Coast Air Quality Management District

Florida

Department of Transportation

New York

New York State Energy Research and Development Authority
New York City Department of Environmental Protection

Pennsylvania

Bureau of Vehicle Management

PRIVATE INDUSTRY

Associations

Automobile Association of America
Automobile Parts and Accessories Association
Automobile Parts Rebuilders Association
Automobile Parts Distributers Association
Association of Diesel Specialists
Engine Manufacturers Association
Motor Equipment Manufacturers Association
Motor Vehicle Manufacturers Association
National Automobile Dealers Association
Oxyginated Fuels Association

Fleet Operators

Bank of America

Laboratories and Consultants

Acurex Corporation
Jet Propulsion Laboratory
Mitre Corporation
Southwest Research Institute
Bill Lowrey, consultant on methanol production
Professor Richard Pefley, University of Santa Clara

Petroleum or Methanol Producers

Amoco
Arco
Celanese
Sun Refining and Marketing Company
Tenneco

Vehicle and Engine Manufacturers

Chrysler
Cummins Diesel
Ford Motor Company
General Motors
Honda Motors
MAN
Nissan Motors
Toyota
Volkswagen

COMPARISON OF METHANOL, GASOLINE, AND DIESEL FUEL

The different chemical composition of methanol, gasoline, and diesel fuels result in substantially different fuel properties. Methanol, unlike gasoline and diesel, is a homogenous liquid made up of a single type of molecular compound. Gasoline and diesel are complex heterogenous mixtures of many different molecules that are blended together in order to achieve a specified set of characteristic properties. Methanol is also unique among the group due to the presence of an oxygen atom in its molecule, which is why methanol is known as an oxygenate, or oxygenated fuel. Almost 50 percent of methanol's molecular weight is comprised of oxygen. None of the petroleum derived molecules in gasoline or diesel contain any oxygen atoms. Table II.1 lists approximations of several fuel properties. A brief explanation of the term and its significance follows the table.

Table II.1
Comparative Fuel Properties

Property	Methanol	Gasoline	Diesel
Average molecular weight	32.04	91	226
Lower heating value (Btu/gal.)	56,560	115,400	129,500
Stoichiometric air/fuel ratio	6.4:1	14.5:1	14.6:1
Autoignition temperature (°F)	878	495	600
Flammability limits (Vol % in air)	6.7-36	1.3-7.6	0.6-5.0
Heat of vaporization (Btu/lb)	506	150	95
Vapor pressure (Reid, psi)	4.6	7-15	0.4
Octane (R+M/2)	110[a]	87.5-93	37.5
Cetane	0-5	5	40

[a]Research method octane only. According to a methanol vehicle expert, motor method octane test parameters are not valid for methanol engines.

Molecular weight - the sum of the atomic weight of each atom in a molecule. The molecular weight shown for gasoline and diesel is an approximate average for "typical" unleaded regular and type 2-D diesel molecules. An average is necessary since both gasoline and diesel have a complex and variable composition of many different molecules. The molecular weight is shown to give an indication of the relative size of the molecules in each fuel.

Lower heating value - the amount of heat given off when a fuel is burned in an engine. Lower indicates that any water vapor contained in the combustion gas does not condense, which would increase the amount of available heat. As shown in table II.1 gasoline and diesel have about 2 and 2.3 times methanol's heating value, respectively.

Stoichiometric air/fuel ratio - indicates the relative proportions of air and vaporized fuel which enable complete combustion of a given amount of fuel without excess air. While gasoline and diesel have similar A/F ratios, more than twice as much fuel is needed for a methanol engine.

Autoignition temperature - the minimum temperature at which the least amount of fuel will self-ignite in air at an atmospheric pressure. This factor is important to compression ignition diesel-type engines that rely on autoignition to initiate combustion. Table II.I shows that methanol's autoignition temperature is nearly 50 percent higher than diesel.

Flammability limits - indicate the volume percent of fuel in air that will sustain combustion at atmospheric pressure and ambient temperature. When the fuel percentage is below the lower limit, there is insufficient fuel for combustion, and when the fuel percentage is above the upper limit, not enough air is present to maintain combustion. As indicated in table II.1, methanol has the widest flammability limits of the three fuels.

Heat of vaporization - also known as the latent heat of vaporization, is the amount of heat energy necessary to change a given quantity of fuel from a liquid to a gas. This is important since engines must vaporize liquid fuel for combustion. Methanol has the highest heat of vaporization compared with gasoline and diesel. While this property is one of the factors behind methanol's cold starting problems, it also offers some potential benefits such as a cooling effect which can increase the density of the air/fuel mixture entering the engine. This cooling effect could eliminate the need for intercoolers with turbochargers.

Vapor pressure - in general is the amount of pressure exerted by the vapors of a volatile liquid on the walls of a closed space. Since vapor pressure varies with temperature, the amount of dissolved air present, and the volume of the space, gasoline is usually categorized in terms of Reid vapor pressure which provides carefully defined conditions for vapor pressure testing. The vapor pressure of gasoline is seasonally adjusted by varying the chemical composition. Higher vapor pressure is desirable in the winter to help cars start. Summer gasoline has a lower vapor pressure to prevent vehicle stalling from vapor lock. Methanol's low vapor pressure compared with gasoline is another factor (along with methanol's high heat of vaporization) behind cold starting problems. In addition, methanol has a single boiling point (149°F) unlike gasoline which is a mixture of hydrocarbons that boil at a range of temperatures. Gasoline vapor pressure can be adjusted by varying the mix.

Octane - a rating usually applied to fuel used in spark ignition engines. Octane measures a fuel's resistance to autoignition. Premature ignition causes knock and loss of power in spark ignition engines. Methanol is a high octane fuel, which enables engine designers to use higher compression engines and/or more spark advance which produce better thermal efficiency and more power.

Cetane - a rating usually applied to fuels used in compression ignition engines. Cetane measures how quickly a fuel will auto ignite. The higher the cetane rating, the shorter the ignition delay. Current compression ignition diesel engines require a cetane rating of at least 40, while methanol has a cetane rating of essentially zero.

METHANOL BUS ENGINES

THE DDA METHANOL ENGINE

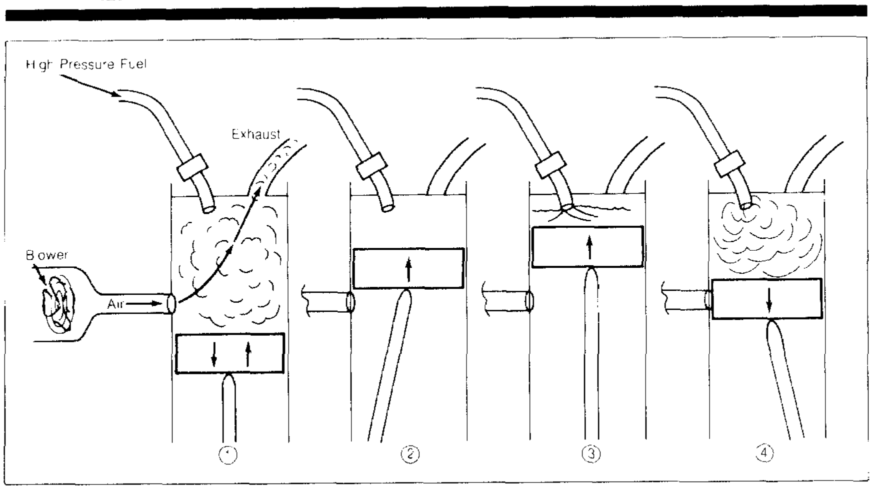
In July 1982 engineers at GM's Detroit Diesel Allison Division (GM/DDA) successfully compression ignited methanol in a single cylinder test engine for the first time. Thirteen months later, Methanol One, GM's first methanol-powered bus, was shipped to California for fleet testing. Methanol had traditionally been considered a poor fuel for compression ignition diesel type engines due to its low cetane rating. The engine in Methanol One is a first-of-a-kind experimental engine. As such, it is basically a diesel engine converted to operate on methanol and has not been optimized for operation on methanol. Further development is required to improve fuel consumption and exhaust emissions.

The DDA heavy-duty methanol engine more closely resembles the diesel than any other methanol bus engine now under development. The engine is the only one to use a two-stroke compression ignition cycle. Two stroke means that the piston moves up and down once to accomplish fuel combustion and exhaust. Compression ignition occurs when fuel sprayed into the hot compressed gases in the cylinder ignites from the heat of the compressed gases without the need for a spark. A schematic of engine operation is shown in figure III.1.

In order to ignite a fuel by compression it must have an adequate cetane value and the compressed cylinder gases must be hot enough. Cetane value is a measure of how quickly a fuel will self-ignite in air heated by compression. The higher the cetane number, the easier it is to start and maintain combustion.

Conventional diesel engines require a fuel with a cetane value of about 40 to maintain combustion. Methanol, at room temperature, has a cetane value between 0 and 5. Because of this, methanol was not thought to be a good substitute for diesel fuel in compression ignition engines. However, engineers at DDA found that compression ignition of methanol is possible if a larger proportion of hot exhaust gas is maintained in the cylinder than in a diesel engine. The additional heat from the exhaust gas facilitates compression ignition of methanol. When the engine is cold, or running at low load, a glow plug provides the necessary heat.

Figure III.1
Schematic of DDA 2-Stroke Engine



(1) Piston at bottom position, blower pushes air into cylinder, forcing some of the hot exhaust gas out through the exhaust port.
(2) Piston rises, air inlet and exhaust closed, mixture of exhaust gases and combustion air is compressed to 1/19 its original volume, causing it to heat up.
(3) Fuel is injected into the compressed air/exhaust gas mixture which is hot enough to cause the fuel to ignite.
(4) Expansion of burning fuel forces piston down.

THE MAN METHANOL ENGINE

Methanol Two uses a four-stroke stratified charge, lean burn, spark-ignited engine that is completely different than the DDA engine. In a way, this engine is a cross between the 4-stroke diesel engine and the spark ignited Otto cycle engine commonly found in conventional automobiles. Like the diesel, fuel and air enter a high compression cylinder separately. However, the engine uses a spark plug in order to ignite the methanol. Unlike the DDA 2-cycle engine, the MAN engine is 4-cycle. This means that each piston travels up and down the cylinder twice to complete an intake, compression, power, and exhaust cycle. This engine also uses a stratified charge, lean burn technique which means that the fuel/air mixture is fuel-rich at the injector/spark plug end of the cylinder but fuel lean elsewhere in the cylinder. This reduces the total amount of fuel that would be needed if the fuel/air mixture was constant throughout the cylinder.

MAN has been working on methanol-fueled engines for about 15 years. As a result, its methanol engine is more highly refined than the DDA engine. MAN also modified the transmission in its methanol bus to provide more efficient operation and added a catalytic converter to reduce exhaust emissions.

Glossary

Catalytic converter	A device that uses engine exhaust heat and chemical catalysts to reduce automotive emissions of regulated pollutants. Oxidizing catalysts are used to control carbon monoxide and hydrocarbon emissions. Reducing catalysts are used to control nitrogen oxide emissions.
Combustion chamber	The location in the engine where fuel is burned.
Corrosion	A chemical action, usually oxidation, that gradually wears, weakens, or destroys metals.
Cylinder	In an engine, the cylinders contain the pistons.
Dissociation	A process that uses heat and catalysts to change larger, more complex molecules into chemical compounds with smaller simpler molecules. For example, methanol (CH_3OH) can be dissociated into carbon monoxide (CO) and hydrogen (H_2).
Elastomers	Elastic substances that have properties resembling rubber.
Energy-equivalent basis	Comparing mpg for methanol and gasoline or diesel requires an adjustment to compensate for methanol's lower volumetric energy content. Gasoline and diesel have 2 and 2.3 times methanol's energy content, respectively. To compare pure methanol mpg performance with gasoline or diesel on an energy-equivalent basis, multiply methanol mpg by 2 for comparison with gasoline and 2.3 for diesel. To compare M85 with gasoline, multiply M85 mileage by 1.76.
Exhaust gas recirculation	A technique used in vehicles to help control nitrogen oxides emissions. The system recirculates some exhaust gas into the intake air to lower the combustion temperature.
Flame arrester	A device with small apertures which allow fluids to pass, but will prevent possible ignition sources from entering the fuel tank.

Flammability limits	The upper and lower flammability limits indicate the percentage of combustible vapor in air above and below which flame will not propigate.
Flash point	The temperature to which a flammable liquid must be heated in order to form sufficient flammable vapor to flash, or ignite, when brought into contact with a flame.
Fuel injection	A type of equipment used to atomize fuel prior to combustion. It provides superior and more precise fuel atomization than carburetors. Multiport fuel injection uses separate fuel injectors for each cylinder in the engine. Throttle body fuel injection uses one or two fuel injectors that are mounted above the intake manifold in a manner similar to a carburetor.
Glowplugs	A device similar to a spark plug which has a centerpiece heated by a resistance wire. It is used to provide a hot spot for surface ignition of the fuel during starting.
Surface ignition temperature	The temperature of a heated surface that is sufficient to ignite liquid droplets of a flammable mixture.
Lean burn	A combustion technique where more air is present in the air/fuel mixture than would be present in a stoichiometric mixture where precisely enough air is present to completely burn a given amount of fuel.
Low level methanol blends	The use of methanol, with or without co-solvent alcohols, at low concentration (3-5% by volume) as octane enhancers in gasoline.
Methanol fuel	In this report, methanol fuel refers to a liquid fuel comprised of not less than 85 percent methanol with other additives, often called M85.
Octane number	Indicates a fuels' resistance to knock. The higher the number the greater the resistance. Octane numbers are determined by testing the fuel under standardized test conditions. Motor and

	research octane numbers use different test conditions. The octane number that commonly appears on gasoline pumps is the average of the two.
Retrofit	Furnish with new parts or equipment that were not available at the time of manufacture.
Spark plug electrodes	The electrically negative and positive parts of the spark plug between which a spark can travel.
Thermal efficiency	The percentage of heat output in the form of work divided by the total amount of heat input.
Vaporization	The change of physical state from a liquid to a gas.
Volumetric energy content	The chemical energy released when burning a given volume of a fuel. This report uses the lower heating value.

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