Analysis of the Economic and Environmental Effects of Methanol as an Automotive Fuel

September 1989

PREFACE

In July 1989 the President submitted to Congress his Administration's proposals for revising the Clean Air Act. One major component of his plan is the Clean Alternative Fuels Program. This program would replace a portion of the motor vehicle fleet in certain cities with new vehicles that meet stringent air emission limits operating on clean burning fuels such as methanol, ethanol, compressed natural gas, liquefied petroleum gas, electricity, and reformulated gasoline.

This report, released by EPA, is the first in a series of reports that will discuss the economic and environmental issues associated with each of these fuels. The Environmental Protection Agency has committed to prepare reports on the remaining candidate fuels according to the following schedule.

Fuel	Final Report
Compressed Natural Gas	End of November
Ethanol	End of November
Liquefied Petroleum Gas	End of February
Electricity	End of February
Reformulated Gasoline	After receipt of formulation

The ordering for these reports does not represent any preference by the Administration, but is the result of the status and availability of the information and research needed to prepare the reports.

The economic and environmental analyses contained in this and subsequent reports assume the full implementation of the President's Alternative Fuels Program.

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ECONOMIC ANALYSIS OF METHANOL

Current Methanol Market Prices

Currently methanol is a major chemical product (20th largest in terms of volume) but is used in transportation fuels only as a feedstock for MTBE, a gasoline blending agent. As such, methanol is produced to meet very high purity standards at relatively small plants, and is transported via relatively small ships and rail cars. Accordingly, current methanol production and distribution is unable to take advantage of various economies of scale that will be discussed later in this report.

It is important to note, however, that even absent the improved economies of scale, methanol can be competitive with gasoline at current world oil prices.

While prices have fluctuated over the last year, chemical-grade methanol is currently selling in the U.S. for between 40 and 45 cents per gallon.(1,2) Methanol would likely be available from existing producers under long term contracts for around 40 cents per gallon.(3,4) One likely option in the near term is to utilize methanol in a 85 percent methanol/15 percent gasoline blend (M85) in a flexible fuel vehicle that could utilize M85, gasoline, or any blend in between. Blending 15 percent gasoline at the current refinery price of 70 to 75 cents per gallon and adding 23 to 25 cents per gallon for distribution, retail markup, and fuel taxes (the derivation of these values will be discussed later in this report) for M85 yields a current M85 pump price of 68 to 74 cents per gallon. Based on the lower energy content of M85 (since methanol has one half of the energy per gallon of gasoline) and a 5 percent higher energy efficiency with M85 in an FFV, the projected gasoline retail price equivalent of M85 today is 114 to 124 cents per gallon. Since regular unleaded gasoline has been selling for an average of 108 cents per gallon, and premium unleaded for an average of 123 cents per gallon, it is clear that M85 is competitive with current gasoline prices, particularly given that the high octane of M85 makes it a natural competitor to premium gasoline. The State of California has also concluded that chemical-grade methanol is competitive within the range of current prices for regular unleaded gasoline and premium unleaded gasoline.(5)

(1) "Alcohol Week," July 10, 1989.
(2) "Alcohol Outlook," June 1989.
(3) Letter from Alberta Gas Chemicals to EPA, March 22, 1989.
(4) Letter from Hoechst Celanese Corporation to EPA, June 2, 1989.
(5) Letter from Charles R. Imbrecht, Chairman, California Energy Commission, to William K. Reilly, Administrator, EPA, July 6, 1989.

In the long run, methanol should be used in its pure form, as M100, because of its superior environmental benefits. Taking today's methanol price of 40 to 45 cents per gallon and adding 20 to 22 cents per gallon for distribution, retail markup, and fuel taxes (slightly lower than for M85 because an M100 vehicle will require more gallons to travel the same mileage) yields a current M100 pump price of 60 to 67 cents per gallon. Assuming 30 percent higher efficiency for an optimized, dedicated methanol vehicle gives a projected gasoline retail price equivalent for M100 today of 92 to 103 cents per gallon. This projected price range for M100 in an optimized, dedicated methanol vehicle is actually below today's gasoline prices.

Fuel-Grade Methanol Price at the Port

This analysis projects fuel methanol prices on an energy equivalent basis will become even more competitive with gasoline at the pump, based to a large extent on DOE's projections of future natural gas and petroleum prices. However, it is recognized that future energy price projections are problematic and always involve some degree of uncertainty. Major changes in world oil prices could significantly impact the competitiveness of methanol or any other alterantive fuel.

Obviously, one key question is the likely location of new fuel grade methanol plants. These plants are expected to be built in remote locations with large supplies of natural gas for which there is no other competitive market. Such locations are numerous and include Alaska's North Slope, Western Canada, Australia, Trinidad, Nigeria, South America, Chile and the Persian Gulf. Only about 15 percent of the unmarketed gas (i.e., that gas associated with oil production which is flared, vented, or reinjected) is located in the Middle East. (See Attachment 1 for more details.)

Obtaining methanol from non-OPEC countries would diversify energy sources and improve this country's energy security.(1) It also provides competition with OPEC oil which could hold down future oil price increases.(2)

The cost of fuel methanol delivered to the U.S. is the sum of two costs: 1) the cost of producing the methanol, and 2) the cost of transporting it to the U.S., if it is produced at remote locations. Both of these costs vary depending on the location of the plant. The following two sections project methanol production and overseas transportation costs at a number of probable locations and derive current best estimates for these costs.

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(1) "Energy Security - A Report to the President of the United States," U.S. Department of Energy, March 1987.

(2) "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector," U.S. Department of Energy, January 1988.

Cost of Fuel Methanol Production

Fuel methanol can be produced from a variety of sources, including natural gas, coal, biomass, and cellulose. The most economical source currently, however, is natural gas, and this is likely to persist well into the 21st century. Currently about 6 billion gallons per year of methanol are produced from natural gas worldwide, for use as a chemical as well as in MTBE production. The present selling price for chemical grade methanol is about 40-45¢/gal.(1,2) However, the production cost of fuel methanol is expected to be considerably lower for two reasons.

First, if a substantial demand for methanol fuel were established, production facilities would be expected to be much larger than present chemical market facilities. Current chemical methanol demand is only a small fraction of what demand could be under a widespread clean fuel program. Higher demand would allow for the construction of large multitrain facilities, which would benefit significantly from economies of scale. Second, these large production volumes would likely spur the development of newly emerging technology for producing methanol (including catalytic partial oxidation, fluidized bed and liquid-phase synthesis). Some of these technologies are already near commercial status and would reduce methanol prices even further via lower plant capital costs and higher process efficiencies; however, this improved technology was not assumed in the EPA fuel methanol price projections.

In estimating the future price of fuel grade methanol, careful consideration should be given to a number of key factors, which include the availability and price of natural gas feedstock, the capital investment required for a new plant, the annual capital recovery rate (CRR), and operating costs.

Under a scenario where there is a substantial, consistent demand for fuel methanol, large scale methanol production facilities (at least 10,000 tons per day (tpd)) could be built to serve the market. The cost (per ton of capacity) of such facilities would be somewhat less than current facilities (less than 2,500 tpd) due to favorable economies of scale. In a recent study by Bechtel, Inc., the required investment for six conventional technology 10,000 tpd plants located at various world sites was estimated.(3) Total projected capital

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(1) "Alcohol Week," July 10, 1989.
(2) "Alcohol Outlook," June 1989.
(3) "California Fuel Methanol Cost Study," prepared by Bechtel, Inc., for Chevron U.S.A., Inc., Amoco Oil Company, ARCO Products Company, California Energy Commission, Canadian Oxygenated Fuels Association, Electric Power Research Institute, Mobil Research and Development Corporation, South Coast Air Quality Management District, Texaco Refining and Marketing, Inc., Union Oil Company of California, January 1989.

investment (including on- and off-site costs, field costs, owner costs, and contingency) ranged from $883 million in the U.S. Gulf Coast to $1,537 million at Dampier, Australia. Key information on each of the sites is presented in Table 1. These investment costs could well be lower, since only conventional technology (i.e., that already in use) was assumed. Bechtel estimated that if emerging technologies were implemented, such as catalytic partial oxidation, required investment might be reduced by about 13 percent. Emerging methanol synthesis technologies, such as fluidized bed and liquid-phase synthesis could also provide additional savings. Other studies have projected even larger reductions.(1,2,3)

Although Bechtel's plant investment estimates do not reflect improved technology, they do provide a conservative baseline estimate of the cost of constructing fuel methanol facilities. The actual impact of these investment costs on the price of methanol depends on the annual capital recovery rate (CRR) or the annual cost of supporting the given investment. The CRR is a complex function involving (among other things) plant life, cost of capital, and income tax rates. Estimates of the annual CRR for methanol plants can vary widely and have a major impact on the calculated cost of methanol produced.

A study by Jack Faucett Associates of historical (1977-85) financial data showed that a real after-tax return on total investment of 5 percent was typical for the U.S. petroleum refining industry.(4) While the return on investment used as a criterion in corporate spending decisions may be higher than this, the fact remains that, once in operation, both new methanol plants and new gasoline refineries will likely return the same rate on capital investments. An after-tax return on investment of 10 percent(5) will be used here, to account for

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(1) "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report Two: Executive Summary--Methanol and LNG Production and Transportation Costs," Office of Policy, Planning, and Analysis, U.S. DOE, May 1989.

(2) "Australia as a Potential Source of Methanol for the California Clean Fuels Program," BHP Petroleum FTY LDT, January 1989.

(3) Letter from K. Mansfield, ICI Chemicals and Polymers Limited, to Charles L. Gray, Jr., U.S. EPA, May 25, 1989.

(4) "Butane Suppliers: An Industry Profile and Analysis of the Impacts of Decreased Market Prices Caused by Gasoline Volatility Control," prepared by Jack Faucett Associates for U.S. EPA, February 1988.

(5) Letter From George E. Crow, Manager, Fuels Planning, Sun Refining and Marketing Company to Charles L. Gray, Jr., U.S. EPA, May 31, 1989.

Table 1

Bechtel Methanol Plant Information

Location	Trinidad	Mid East	Australia	Canada	US Gulf	Alaska
Total Capital Cost (Million 1988 $)	985	1088	1537	926	883	1498
Annual Natural Gas Consumption (bcf)	109.6	109.6	109.6	109.6	109.6	109.6
Annual Methanol Production (million gal)	1151	1151	1151	1151	1151	1151

the likelihood that: 1) these years were atypical, and 2) a methanol plant may, especially initially, entail more risk. Assuming a 15-year plant life, this translates into an annual CRR of 16.2 percent. (Note that methanol production costs increase approximately 1 cent/gallon for each 1 percent increase in CRR at a typical facility.) A recent study by SRI International(1) for oil companies marketing in California used a real after-tax return on investment of 11.4 percent for plants which would be located in developed countries and a real after-tax return on investment as high as 14.3 percent for plants built in Trinidad and Saudi Arabia.(2)

When a CRR of 16.2 percent is applied to the investment values shown in Table 1, annual investment related costs ranging from \$143 million to \$249 million (12.4-21.6¢/gal) result. These are shown for each of the six sites evaluated in the Bechtel study in Table 2. The sensitivity of methanol costs to CRR is discussed in more detail in Attachment 3.

Non-gas operating costs for the six plants are also shown in Table 2. These values were also taken from the Bechtel study and include such things as utilities, operating labor and supplies, maintenance, insurance, etc. These range from 5.4 to 9.4 cents per gallon.

By far the most sensitive and controversial factor influencing methanol cost is the price at which natural gas is available as a feedstock. With current technology plants, the price of methanol is increased by about 10¢/gal for every \$1 per million Btu (MMBtu) increase in the price of natural gas. The price at which natural gas is available, in turn, is dependent on the price of competing energy sources (crude oil, coal, etc.), the existence or nonexistence of an alternative market for the specific gas, and the cost of collecting and transporting the gas to the plant. In highly developed areas, such as the U.S. Gulf Coast, an extensive gas pipeline infrastructure exists to supply domestic demand, therefore linking the value of natural gas to other industrial energy prices. On the other extreme, in remote locations, such as Prudhoe Bay, the natural gas co-produced with oil is reinjected back into the wells at a negative cost because no market for natural gas exists, nor is one likely to develop in the near future, and thus the natural gas has little market value. The price at which natural gas could be supplied to a methanol plant at such a location would thus be minimal, reflecting only the costs of collection and transport to the

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(1) "The Economics of Alternative Fuels and Conventional Fuels," SRI International, February 2, 1989.

(2) "Capital Servicing Costs of Fuel Methanol Plants," William E. Stevenson, Bechtel Financing Services, Inc., May 3, 1989.

Table 2

Cost of Fuel Methanol Delivered to U.S.
(¢/gal)

	Trinidad	Mid East	Australia	Canada	US Gulf	Alaska
Natural Gas	5-10	5-10	5-10	10-25+	15-35+	3-10
Nongas Operating	5.9	7.1	9.1	5.4	5.6	9.4
Capital Recovery Cost	13.9	15.3	21.6	13.0	12.4	21.1
Total Production Cost	25-30	27-32	36-40	28-43+	33-53+	33-40
Transport Cost	5.0	5.0	4.0	8.0	0	8.0
Total Delivered Cost	30-35	32-37	40-45	36-51+	33-53+	41-48

local facility. For example, natural gas could be available to the Prudhoe Bay, Alaska site at less than $0.50/MMBtu over the next 20 years.(1) In other remote locations, given the vast quantity of natural gas which is currently vented and flared, it seems likely that gas can be supplied at similar prices. Based on a recent DOE analysis, prices ranging from $0.50-1.00/MMBtu appear reasonable, thus contributing 5-10¢/gal to the price of methanol for many sites.(2) (The SRI study projected somewhat higher natural gas prices at several of the same remote sites, and although not used as "best estimates", the SRI values are considered in the sensitivity analysis in Attachment 3.) In developed areas such as the U.S., high natural gas prices are likely ($1.50/MMBtu or more) and will probably prohibit the competitive production of fuel grade methanol until oil prices rise significantly. For western Canada, which has no developed natural gas market, but could be connected to the U.S. distribution system at a moderate cost, an intermediate price for natural gas of $1.00-1.50 per MMBtu or higher is likely. As petroleum prices rise in the future, it seems reasonable to expect upward pressures on all natural gas. However, considering the diversity of supply of natural gas and the absence of competing uses of the gas at most locations, the energy price rise of remote natural gas should be slower than that of petroleum.

In summary, natural gas prices of $0.50-1.00 MMBtu in remote areas should allow for gas related costs of 5-10¢/gal of methanol. When this is added to the total non-gas costs shown in Table 2, total production costs of 25-35¢/gal is estimated for low-cost areas.

Overseas Transportation and Total U.S. Port Costs

Also shown in Table 2 are transportation costs, which were projected in the Bechtel report (with one exception). Bechtel's estimates range from 4 to 9¢/gal for all sites except Prudhoe Bay, Alaska, where transportation costs of 52¢/gal were suggested based on the assumption that a new Trans-Alaska methanol pipeline would be required for methanol. The Bechtel study ignores the projected decline in the throughput of the existing Trans-Alaska pipeline, which will create spare capacity over the next several years. Thus, the transportation cost for Alaskan methanol has been estimated at 8¢/gal, comparable to that of Canada.

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(1) "The Economics of Alternative Fuels and Conventional Fuels," SRI International, presented to the Economics Board on Air Quality and Fuels, February 1989.

(2) "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report Two: Executive Summary--Methanol and LNG Production and Transportation Costs," Office of Policy, Planning and Analysis, U.S. DOE, May 1989.

Table 2 shows the total landed cost estimates for methanol. As can be seen, costs in the 30-40¢/gal range are typical for the low-cost sites. The mid-point of this range, 35¢/gal, will be used as an estimate for this analysis. This is within the range of methanol price estimates developed by several other analysts.(1-12)

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(1) "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report Two: Executive Summary--Methanol and LNG Production and Transportation Costs," Office of Policy, Planning and Analysis, U.S. DOE, May 1989.

(2) "Australia as a Potential Source of Methanol for the California Clean Fuels Program," BHP Petroleum FTY LTD, January 1989.

(3) "Statement by ICI on the Proposed SCAQMD Phase Out Policy," letter to Mr. Paul Wuebben, SCAQMD from G. D. Short, ICI Products, December 6, 1988.

(4) Letter to Ms. Jananne Sharpless, Secretary of Environmental Affairs, State of California from R. Colledge, Canadian Oxgenated Fuels Association, April 3, 1989.

(5) Letter to Charles L. Gray, Jr., U.S. EPA from J.J. Hennessey, Vice President and General Manager, Alberta Gas Chemicals, Incorporated, March 22, 1989.

(6) Letter to Honorable Jananne Sharpless, Secretary of Environmental Affairs, State of California from Peter J. Booras, President, Yankee Energy Corporation, January 9, 1989.

(7) Letter To Jeffrey A. Alson, U.S. EPA from Chris Grant, Alberta Gas Chemicals, Incorporated, April 28, 1989.

(8) Letter to Charles L. Gray, Jr. U.S. EPA, from R. D. Morris, Hoechst Celanese, April 27, 1989.

(9) Letter to Charles L. Gray, Jr., U.S. EPA from R.D. Morris, Hoeschst Celanese Corporation, June 2, 1989.

(10) "Conversion of Offshore Natural Gas to Methanol," Phase I Report, Federal Highway Administration, U.S. Department of Transportation, Contract: DTFH-61-85-C-0076, Yankee Energy Corporation, May 1987.

(11) Letter to Charles L. Gray, Jr., U.S. EPA, from John Meyers, President, Fuel Methanol of America, Inc., January 4, 1989.

(12) Letter to Charles L. Gray, Jr., U.S. EPA, from Y. Mizukami, General Manager, Energy and Chemical Project Manager, Marubeni Corporation, December 27, 1988.

Retail Price of Methanol and the Gasoline-Equivalent Price

The cost of moving fuel methanol from port to pump includes several components: distribution, service station markup, and state and federal taxes. Attachment 2 contains a discussion of EPA's estimates of these costs which are 20 to 22 cents per gallon making the retail price of methanol fuel produced in large volumes 55 to 57 cents per gallon.

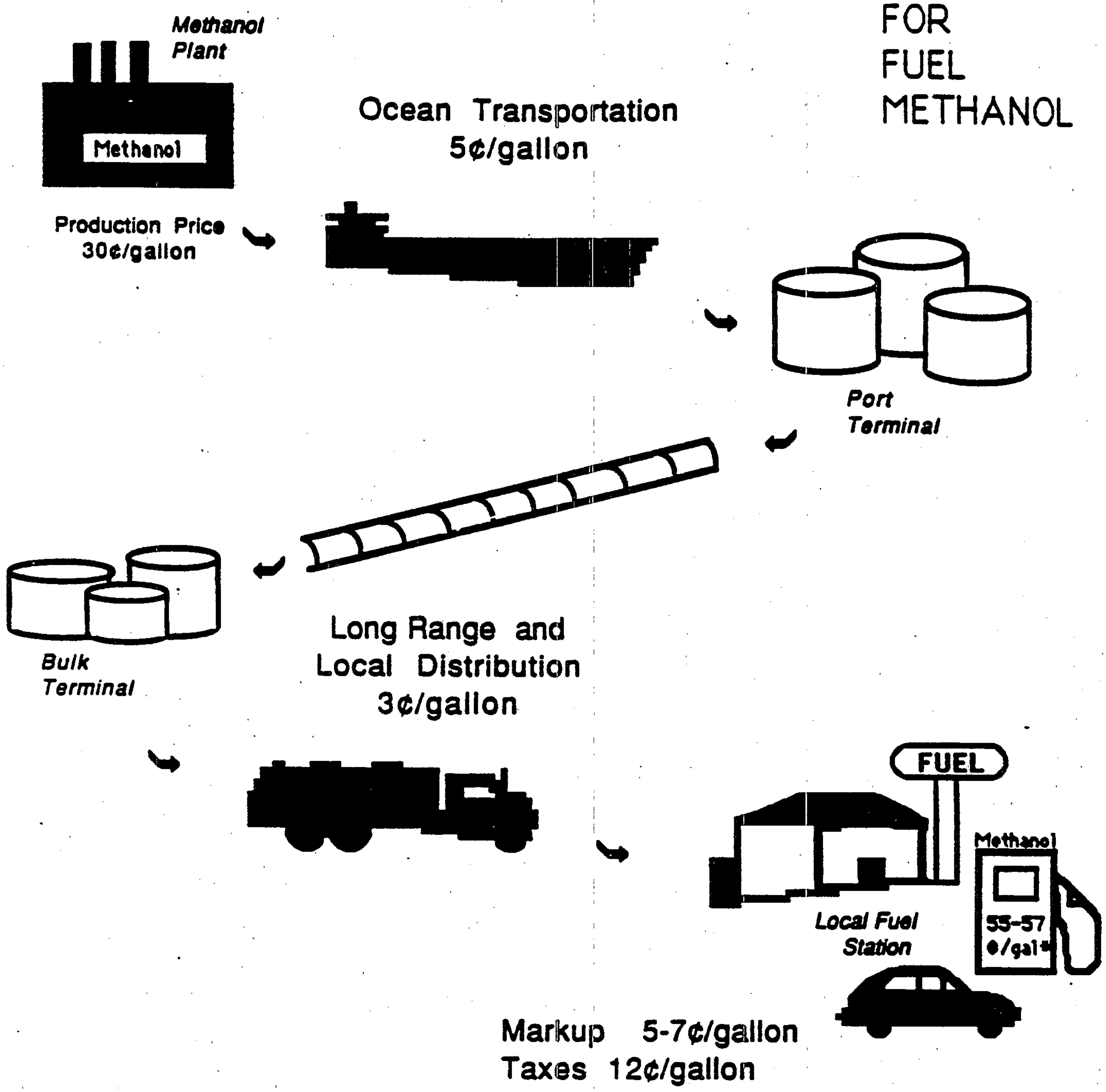
Figure 1 illustrates the various components that make up the overall price that the consumer would likely pay at the pump for fuel methanol under the proposed program. It is important to again emphasize that these economics are dependent on a market demand certainty for the fuel methanol and on a large volume of fuel.

Methanol has one-half the energy on a per gallon basis as compared to gasoline, primarily because half of the methanol molecule is oxygen which has no energy value. Accordingly, methanol vehicles always yield lower miles per gallon values compared to gasoline. But from an energy conservation and cost viewpoint, energy efficiency is the more important criterion, and methanol can be a more energy efficient fuel than gasoline. Attachment 2 also contains a discussion of the fuel efficiency increases that can be expected from optimized, dedicated methanol vehicles and concludes such vehicles can be up to 30 percent more energy efficient than comparable gasoline vehicles.

Flexible-fueled methanol vehicles are projected to achieve efficiency improvements of 5 percent relative to gasoline. Thus, such vehicles would require 1.90 gallons of methanol to travel the same distance as a gasoline fueled vehicle on one gallon of gasoline. For a 30 percent more energy efficient vehicle, only 1.54 gallons of methanol would be needed per gallon of gasoline. Therefore, the gasoline-equivalent methanol retail price is simply the methanol retail price, multiplied by the ratio that accounts for the number of gallons needed for a methanol vehicle to travel the same distance as a gasoline vehicle on a gallon of gasoline. For a 5 percent efficiency improvement the ratio is 1.90; for a 30 percent efficiency improvement the ratio is 1.54. As shown in Table 3, the gasoline-equivalent methanol retail price for a 5 percent efficiency improvement methanol vehicle would be $1.05 to $1.09 per gallon. The gasoline-equivalent methanol retail price for a 30 percent better efficiency methanol vehicle would be $0.85 to $0.88 per gallon.

Figure 1

SUPPLY LOGISTICS FOR FUEL METHANOL



* Gasoline equivalent price of 105-109 ¢/gallon with a flexible-fueled vehicle and 85-88 ¢/gallon with an optimized, dedicated vehicle.

Table 3

Gasoline-Equivalent Methanol Retail Price
(cents per gallon)

	5% Better Efficiency	30% Better Efficiency
Methanol Port Price	35	35
Distribution, Markup, and Taxes	20-22	20-22
Total Methanol Retail Price	55-57	55-57
Gasoline-Equivalent Ratio	1.90	1.54
Total Gasoline-Equivalent Methanol Retail Price	105-109	85-88

Current Gasoline Price Compared to Methanol

Currently, about 72 percent of unleaded gasoline sales are regular unleaded at an average pump price of $1.08. The remainder of unleaded sales is premium with an average price of $1.23. Thus, the sales weighted average cost of gasoline today is $1.12.

The gasoline-equivalent methanol price for 5 percent efficiency improvement vehicles of $1.05-1.09 is competitive with present gasoline prices, and the dedicated vehicle equivalent price of $0.85-0.88 is much cheaper. Therefore, methanol-fueled vehicles would be attractive even at today's petroleum prices.

Future Gasoline and Methanol Prices

Predicting the relationship between future gasoline and methanol prices is somewhat more difficult, especially with scenarios where crude oil prices increase. Future gasoline price increases will most likely cause natural gas feedstock prices to increase as well. We estimate that remote natural gas prices would increase, but at a lesser rate than gasoline (based on the fact that the remote gas has no other competitive market and it is not controlled by a cartel). This would cause increased price competition with gasoline, with methanol increasing its market share or gasoline prices being suppressed. Obviously, if this occurred, there would be substantial savings to the U.S. economy.

A more detailed discussion of fuel methanol and gasoline prices, and their inter-relationship, is contained in Attachment 3.

Vehicle Costs

From EPA's discussions with vehicle manufacturers with respect to dedicated methanol vehicles and EPA's analysis, there are several areas that have been identified where cost savings over gasoline vehicles will be likely and several areas in which cost increases will be likely. Overall, this analysis suggests there will be no net cost difference between dedicated methanol vehicles and future gasoline vehicles. Such a conclusion is also supported by Congressional testimony in 1984 given by both Ford and General Motors.(1)

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(1) Responses by Helen Petrauskas, Ford Motor Company, and Robert Frotsch, General Motors Corporation, to questions at the Joint Hearing by the Subcommittees on Fossil and Synthetic Fuels and Energy Conservation and Power, April 25, 1984.

In determining the incremental costs of FFVs, the fuel sensor which identifies the type of fuel in the vehicle (methanol, gasoline, or a blend) is one of the more costly items. Other costs are added to assure engine and fuel system compatibility with both fuels and to reflect an increased fuel tank size. Overall, the EPA estimate, based on discussions with auto company engineers, is that an FFV will have up to a $300 cost incremental to a comparable gasoline vehicle.

These vehicle cost estimates are described in more detail in Attachment 4.

ENVIRONMENTAL ANALYSIS OF METHANOL

Urban Ozone Levels

The primary environmental benefit associated with the alternative fuels program will be significant improvements in ozone levels in the most seriously polluted areas of the country. The clean, alternative fuel advantage over gasoline in terms of urban ozone formation is due to both lower levels of vehicle emissions and the lower photochemical reactivity of these emissions.

The VOC emissions from methanol vehicles, for example, consist of mostly unburned methanol, a simple compound with a reactivity of only one-fifth that of average gasoline vehicle hydrocarbon emissions. Smaller quantities of hydrocarbons and formaldehyde are also emitted from methanol vehicles (formaldehyde possesses approximately twice the reactivity of gasoline hydrocarbon). On a reactivity-equivalent basis, methanol flexible fuel vehicles (FFVs) are projected to emit at least 30 percent less volatile organic compounds (VOC) than typical future in-use gasoline vehicles, while optimized, dedicated methanol (M100) vehicles are projected to emit 80 percent less VOC than future gasoline vehicles.(1,2,3,4,5)

Passenger cars and light-duty trucks typically are responsible for approximately 87 percent of all motor vehicle related VOC emissions. If all passenger cars and light trucks in a given metropolitan area were optimized, dedicated methanol vehicles that emitted 80 percent less VOC than gasoline vehicles, then these vehicles would reduce the motor vehicle VOC in that area by an average of 70 percent. Assuming that motor vehicles will be responsible for just 20 percent of all VOC in such an area, this would reduce total VOC in 2015 by about 14 percent.

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(1) "Guidance on Estimating Motor Vehicle Emission Reductions from the Use of Alternative Fuels and Fuel Blends," U.S. EPA, EPA-AA-TSS-PA-87-4, January 29, 1988.

(2) "The Emission Characteristics of Methanol and Compressed Natural Gas in Light Vehicles," Jeffrey A. Alson, U.S. EPA, APCA Paper No. 88-99.3, June 1988.

(3) "Effects of Emission Standards on Methanol Vehicle-Related Ozone, Formaldehyde, and Methanol Exposure," Michael D. Gold and Charles E. Moulis, U.S. EPA, APCA Paper No. 88-41.4, June 1988.

(4) "Fuel Economy and Emissions of a Toyota T-LCS-M Methanol Prototype Vehicle," J.D. Murrell and G.K. Piotrowski, U.S. EPA, Society of Automotive Engineers Paper No. 871090, May 1987.

(5) "Air Quality Benefits of Alternative Fuels," EPA Report for Alternative Fuels Working Group Report of the President's Task Force on Regulatory Relief, July 1987.

The VOC emission reductions achievable with the clean, alternative fuels program are a significant portion of what could be achieved by taking the same number of cars off the road, and are much larger than the reductions that would be available from any other motor vehicle VOC control program absent major vehicle use restrictions.

Air Toxics

The use of methanol in motor vehicles will also reduce the air toxics impacts of motor vehicle emissions. Considering the pollutants which are emitted from gasoline vehicles and classified by EPA as either known or probable human carcinogens, projected reductions in the number of cancer cases as a result of a clean fuels program are significant. The elimination or reduction of emissions of benzene, gasoline refueling vapors, 1,3-butadiene, and polycyclic organic material (POM) would be responsible for most of the projected cancer reductions.(1,2,3)

Methanol is not generally considered a toxic air pollutant at levels likely to be encountered from use as a motor vehicle fuel.(4) Available information indicates that methanol is not carcinogenic. Additional research is being conducted, however, on the health effects of methanol to provide an even broader base of health effects information.

Formaldehyde exposure is an important air toxics issue often raised as a concern with the use of methanol. Formaldehyde is classified by EPA as a probable human carcinogen. There is some concern since burning methanol produces formaldehyde and most prototype methanol vehicles have emitted more formaldehyde than gasoline vehicles. Catalytic

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(1) "Unregulated Exhaust Emissions from Methanol-Fueled Cars," L.R. Smith, C. Urban, T. Baines, Society of Automotive Engineers Paper 820967, August 1982.

(2) "Characterization of Emissions from a Methanol Fueled Motor Vehicle," Richard Snow, Linnie Baker, William Crews, C.O. Davis, John Duncan, Ned Perry, Paula Siudak, Fred Stump, William Ray, James Braddock, Journal of the Air Pollution Control Association, 39, No. 1, 4854, January 1989.

(3) "Air Toxic Emissions and Health Risks from Motor Vehicles," Jonathan M. Adler and Penny M. Carey, Air and Waste Management Association Paper 89-34A.6, June 1989.

(4) "Automotive Methanol Vapors and Human Health: An Evaluation of Existing Scientific Information And Issues for Future Research," Health Effects Institute Report, May 1987.

converters will be utilized on methanol vehicles to reduce formaldehyde emissions, and levels could be reduced to gasoline levels if necessary. But it is important to note, however, that neat methanol use is not expected to increase the number of cancer cases from formaldehyde exposure. This is because the majority of ambient formaldehyde is not due to direct emissions from vehicles but rather is formed indirectly in the atmosphere through photochemical reactions involving reactive hydrocarbons. Indirect formaldehyde formation with neat methanol vehicles will decrease relative to gasoline vehicles due to the relative decrease in reactive hydrocarbons emitted. With neat methanol use, the decreased amount of indirect formaldehyde formed is expected to offset any increase in direct formaldehyde emissions.(1,2) However, the exposure and health effects tradeoffs between direct formaldehyde emissions and indirect formaldehyde formation will continue to be studied.

Both methanol and formaldehyde can be acutely toxic at elevated concentrations. Concentrations of these pollutants from methanol vehicles could occur in specific localized exposure scenarios, such as personal garages, parking garages, roadway tunnels, etc. EPA has analyzed potential exposures in such scenarios in the recent final rulemaking for methanol fueled vehicles, and has concluded that methanol and/or formaldehyde levels would remain well below the levels of acute toxicity concern except under extreme conditions such as extended idling in personal garages. Such extended idling could also produce very high carbon monoxide emission levels, just as with gasoline vehicles today. Research is ongoing to better identify the public health issues associated with exposure to methanol and gasoline vehicle emissions in these localized exposure scenarios.

Global Warming

The combustion of all carbon-containing fuels yields emissions that are greenhouse gases. However, the global warming implications of using methanol as a transportation fuel have received much attention and scrutiny, as is appropriate for any candidate alternative transportation fuel.

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(1) "Emission Standards For Methanol-Fueled Motor Vehicles and Motor Vehicle Engines," EPA Final Rulemaking, Federal Register Part 86, No. 68, 14426-14613, April 11, 1989.

(2) "Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards and Test Procedures for Methanol-Fueled Vehicles and Engines," EPA Report, January 1989.

For the foreseeable future, the economics of methanol production clearly favor the production of methanol from natural gas. It is anticipated, though not certain, that the methanol will be produced from vented and flared natural gas. If currently vented or flared natural gas is used to produce methanol, a large global warming benefit will accrue, since such gas is currently being wasted while adding to the greenhouse gas burden. If natural gas reserves that are not being vented or flared supply methanol fuel, equal or slightly lower greenhouse gas emissions are projected relative to those of gasoline from crude oil.(1,2) Other things being equal, the use of coal as a methanol feedstock could nearly double greenhouse gas emissions, but improved technology in the future such as methane recovery at the coal mine and carbon dioxide recovery at the production plant could reduce the global warming impact to less than that from gasoline from crude oil. Research should continue in these areas since such technologies need to be developed if coal use is to be considered. The use of cellulose, biomass or other renewable feedstocks to produce methanol could yield a very large global warming benefit, since such materials do not require the use of "stored carbon."

The sale of alternative-fueled vehicles will generate CAFE credits under the Alternative Motor Fuels Act of 1988. To the extent that automobile manufacturers and purchasers accept lower fuel economy of the gasoline-powered portion of the fleet, CAFE could no longer be a binding constraint and an increase in gasoline consumption and global warming could result. This effect would be reduced to the extent that consumers demand good fuel economy and that methanol is produced from currently vented and flared natural gas.

Other Issues

Questions have been raised regarding the use of methanol as a vehicle fuel with respect to fuel spills and human safety. EPA is analyzing these issues and has concluded at this time that, like all fuels, methanol has certain characteristics that justify protective regulatory safeguards. These issues are discussed, along with a more detailed review of the environmental implications of a clean, alternative fuels program, in Attachment 5.

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(1) "Global Warming as Affected by Fuels Choices," Acurex Corporation, prepared for the 1989 SAE Government/Industry Meeting, May 2-4, 1989.
(2) "Transportation Fuels and the Greenhouse Effect," Mark A. DeLuchi, Robert A. Johnson, and Daniel Sperling, U. of California, December 1987.

Attachment 1

Potential Natural Gas Feedstock Availability for Future Methanol Fuel Production Facilities

The production of crude oil often includes a significant quantity of natural gas that is produced along with the crude oil. This "associated" gas is considered a nuisance in remote areas where there is no local market for the gas. Therefore, much of the gas is simply vented or flared. According to DOE estimates, the worldwide volume of natural gas which is vented and flared annually (a contributor to global warming) is roughly 2,975 billion cubic feet (bcf). Using existing conversion technology, this volume of gas would translate into about 31 billion gallons of methanol annually. More than twice this volume of gas is produced with petroleum and is currently being reinjected into oil reservoirs (6151 bcf per year or 64 billion gallons of methanol per year). While some of this gas is used to maintain reservoir pressure, an established methanol fuel market would likely attract a portion of this low-value gas.

Combined, this unmarketed natural gas could supply a total of 95 billion gallons of methanol per year, equivalent to about half the gasoline currently used in the U.S. As can be seen in Table 1, roughly 20 percent of this gas is located in the United States, the majority from the North Slope of Alaska. Approximately 30 percent is located in Africa, 10 percent in South America, 6 percent in the Far East, and 5 percent in Western Canada. Only about 15 percent of flared, vented, or reinjected gas is produced in the Middle East.

Vast quantities of natural gas are co-produced on the Alaskan North Slope and are currently reinjected into the oil reservoirs at significant cost, because there is no pipeline to transport the gas to market. If the gas is converted to liquid methanol, tests have shown that the methanol could be transported through the Trans-Alaskan pipeline to tankers in Valdez. At current reinjection rates this gas could be used to produce approximately 14 billion gallons of fuel methanol annually.

Looking at the long-term picture, estimated proven natural gas reserves total 3,797 trillion cubic feet (tcf) worldwide. Since most of the natural gas reserves have been discovered as a result of oil exploration, projected natural gas resources are much greater.

TABLE 1

Region / Country	Annual Unmarketed Natural Gas (bcf) and Methanol Potential (billion gal/yr): Vented, Flared* (bcf)	Methanol Equivalent** (bil gal/yr)	Reinjected* (bcf)	Methanol Equivalent** (bil gal/yr)	Total Natural Gas Reserves (tcf) and Methanol Potential (billion gals): Proved Reserves* (tcf)	Methanol Equivalent** (bil gals)
NORTH AMERICA						
Canada	88		497		98.0	
Mexico	69		NA		76.5	
United States	98		1,838		187.2	
Total	255	3	2,335	24	361.7	3,747
CENTRAL AND SOUTH AMERICA						
Argentina	6		47		23.6	
Bolivia	4		59		5.0	
Brazil	33		36		3.6	
Chile	0		112		NA	
Colombia	18		14		3.6	
Trinidad and Tobago	108		0		10.4	
Venezuela	90		438		95.0	
Other	50		5		NA	
Total	309	3	711	7	150.1	1,555
WESTERN EUROPE						
France	0		0		NA	
Germany, West	0		0		6.4	
Italy	0		0		10.2	
Netherlands	0		0		64.1	
Norway	6		141		105.9	
United Kingdom	77		113		22.0	
Other	9		24		NA	
Total	92	1	278	3	218.1	2,260
EASTERN EUROPE AND U.S.S.R.						
Germany, East	0		0		NA	
Hungary	0		0		NA	
Poland	0		0		NA	
Romania	0		0		NA	
U.S.S.R.	350		NA		1,450.0	
Other	0		0		NA	
Total	350	4	0	0	1,479.3	15,326
MIDDLE EAST						
Bahrain	0		65		6.9	
Iran	175		430		489.4	
Kuwait	23		2		42.6	
Oman	10		50		9.5	
Qatar	0		0		156.7	
Saudi Arabia	98		67		146.1	
United Arab Emirates	175		56		203.5	
Other	246		0		NA	
Total	727	8	670	7	1,084.1	11,231
AFRICA						
Algeria	275		1,570		105.9	
Egypt	33		0		10.2	
Libya	25		190		25.7	
Nigeria	445		81		84.0	
Other	171		61		NA	
Total	949	10	1,902	20	248.7	2,577
FAR EAST AND OCEANIA						
Afghanistan	0		0		NA	
Australia	0		0		18.6	
Brunei	10		0		7.0	
China	NA		NA		30.7	
India	100		0		17.6	
Indonesia	108		225		73.0	
Japan	0		0		NA	
Malaysia	75		0		52.2	
New Zealand	0		30		5.2	
Pakistan	0		0		22.4	
Other	0		0		NA	
Total	293	3	255	3	255.5	2,647
WORLD TOTAL	**2,975**	**31**	**6,151**	**64**	**3,797.6**	**39,343**

* From Energy Information Administration
** Assuming a 65% natural gas-to-methanol conversion efficiency

In summary, it is clear that a huge resource base of natural gas is available to produce methanol. The natural gas supply is also more geographically diverse than the world oil supply (where about 65 percent of holdings are in the Middle East). Using natural gas as a source of transportation energy would, insofar as petroleum consumption were reduced, also reduce our dependence on oil imports from the Middle East, thus enhancing national energy security. Finally, the potential exists to provide domestic and Canadian sources for a significant amount of the methanol needed for the clean fuels program by utilizing natural gas from the Alaskan North Slope that is currently reinjected at a significant cost and from proven Western Canadian fields that are shut in.

The estimates from DOE used to make the conclusions stated above are given in the following documents:

1. International Energy Annual, 1987, DOE/EIA-0219(87), Energy Information Administration, 1987.

2. Natural Gas Annual, 1987 - Volume II, DOE/EIA-0131(87)/2, Energy Information Admninistration, 1987.

Attachment 2

What Are The Distribution Costs Associated With Fuel Methanol?

The difference between the port price of a fuel and its retail price can be divided into three main components: distribution of the fuel to the service station, service station markup, and taxes. A summary of estimates by EPA and other groups of these primary components is shown in the following table.

Estimates of Fuel Price Components from Port/Refinery to Retail (cents per gallon)

	Typical Gasoline	M100 EPA	M100 EEA(1)	M85 EPA	M85 SRI(2)
Long-range and Local Distribution*	6 (3)	3	3	3	3
Service Station Markup	9	5-7	9	6-8	13
All Taxes	24	12	13	14	15
Total	39 (36)	20-22	25	23-25	31
Total, Gasoline-Equivalent	39 (36)	40-44	50	40-44	62

* 6¢/gallon represents average for U.S. gasoline supply. Long range distribution for gasoline made from a new refinery (likely located on foreign soil) would be similar to those of methanol (3¢/gal) since shipping routes would be similar for either product.

(1) "Distribution of Methanol for Motor Vehicle Use in the California South Coast Air Basin," prepared for the U.S. EPA by Energy and Environmental Analysis, Inc., September 1986.

(2) "The Economics of Alternative Fuels and Conventional Fuels," prepared for several California oil companies by SRI International, February 2, 1989.

The total overall price increment due to fuel distribution, service station markup, and taxes should be slightly higher, on an energy-equivalent basis, for methanol than the price increment for gasoline today.

Long-range distribution through the use of pipelines, barges, and tankers is projected to be significantly less expensive per gallon of fuel for methanol, principally because the most significant ozone nonattainment metropolitan areas tend to be located on the coast or near or on pipelines and major waterways. Thus, methanol produced in foreign locations could be supplied at a lower per gallon distribution cost than gasoline is currently supplied nationwide. To the extent that foreign methanol is compared with gasoline supplied from a new refinery (built on foreign soil), distribution costs should be nearly equal on a per gallon basis. Terminaling costs per gallon are estimated to be virtually the same for methanol as for gasoline, as they tend to be strictly a function of volume. Trucking costs may tend to be slightly lower on a per gallon basis for methanol (higher on a per energy basis) as truck delivery route lengths will tend to be shorter, since the routes can be optimized for methanol fuel deliveries. All in all, however, we project that long-range and local distribution costs for methanol will be similar to those of the other studies summarized above.

The largest area of disagreement concerns service station markup. SRI's estimate, for example, would mean that a service station owner would make 3 to 4 times more money on a methanol customer than a gasoline customer. Perhaps this markup could be justified for a very low volume fuel, but it is unlikely in a stabilized, high methanol fuel demand scenario. Accordingly, at worst the costs of retailing methanol will be the same as for gasoline on a volumetric basis. But it is much more appropriate to assume that the cost per mile driven (or the cost per refueling event) will be equalized, rather than the cost per volume of fuel (put another way, a consumer should be able to go the same number of miles on $10 worth of methanol as with $10 worth of gasoline). Since it will take anywhere from 2 gallons (equal efficiency) to 1.54 gallons (30 percent better efficiency) of methanol to provide the same mileage as gasoline, the markup per gallon of methanol should be closer to one-half to two-thirds that of gasoline.

Some studies have assumed that the number of service stations would need to significantly increase with methanol fuel because more fuel would have to be dispensed. With this assumption, the write-off of the new capital investment against the sales of methanol "justifies" a higher retail markup for methanol. However, this assumption does not seem valid. The need to dispense a larger volume of fuel to fill a larger methanol tank would most logically result in increased dispensing rates and no increase in filling time, instead of the construction of new stations and the acceptance of longer filling times. With methanol's low volatility, increased dispensing rates should be more cost effective than building new stations. The actual time spent filling up the tank is nonetheless only a fraction of the total time spent in the station (e.g., time is also spent pulling in and out, opening and sealing the tank, paying the cashier, buying other goods, etc.). The only costs which would be fully proportional to volume are the pumping costs, which are a small proportion of total station costs. Therefore, it seems reasonable to assume that total retailing costs only increase slightly and that the dealer margin for M100 per gallon will be about 5 to 7 cents per gallon (or 6 to 8 cents per gallon for M85 which has a slightly higher energy content).

Taxes for methanol and gasoline are assumed to be equivalent on a Btu basis, 12 cents per gallon for M100 and 14 cents per gallon for M85. This does not reflect expected increases in fleet average energy efficiency due to the introduction of high-efficiency M100 vehicles, however. As fleet energy efficiency increases, taxes (on a Btu basis) would have to increase to create a "revenue-neutral" program. Any increased taxes would likely be allocated to gasoline and methanol equally on a Btu basis, maintaining the two-to-one ratio used in this analysis.

In summary, EPA estimates the total M100 price increment from port to customer would be about 20 to 22 cents per gallon and the total M85 price increment would be 23 to 25 cents per gallon. Higher estimates are possible under different assumptions but do not appear appropriate for a stabilized, high methanol fuel demand scenario.

For a more detailed discussion on the distribution costs associated with a future methanol fuel market, refer to the documents listed below:

1. "Distribution of Methanol for Motor Vehicle Use in the California South Coast Air Basin," Energy and Environmental Aanlysis, Inc., prepared for U.S. EPA, September 1986.

2. "The Economics of Alternative Fuels and Conventional Fuels," SRI International, prepared for California oil companies, February 2, 1989.

3. "Preliminary Perspective on Pure Methanol Fuel for Transportation, "U.S. EPA Report to Congress, EPA460/3-83-003, September 1982.

4. "The 1986 Bureau of Census State & Metro Area Data Book, & City/County Data Book", Bureau of the Census, U.S. Dept. of Commerce.

5. "The 1982 Census of Retail Trade", Bureau of the Census, Dept. of Commerce.

6. "The 1982 & 1987 FHWA Highway Statistics", Dept of Transportation.

7. "The National Petroleum News Fact Book", 1987 and 1988, Hunter Publications.

8. Lundberg Surveys, which provide data on metro area service station distributions & throughputs.

9. Rand-McNally Motor Carriers' Road Atlas 1989

10. County Road Mileage, US DOT Transportation Computer Center, Washington, D.C.

What Level Of Fuel Efficiency Can Be Expected From An Optimized Dedicated M100 Vehicle?

Methanol has about one-half of the energy per gallon of gasoline, primarily because half of the methanol molecule is oxygen which has no energy value. Accordingly, vehicles fueled with methanol yield lower miles per gallon values compared to those fueled with gasoline. But energy efficiency is the most important criterion in this regard, and methanol is actually a more energy efficient fuel than gasoline.

Methanol has chemical and combustion properties which make it an inherently more efficient fuel than gasoline. The most important properties are its higher octane rating, which allows a higher compression ratio, its wide flammability limits, which permit good combustion at high air-to-fuel ratios, and its higher power output, which allows the use of a smaller, more efficient engine.

Methanol's higher octane allows substantial increases in engine compression ratio from today's values with gasoline-fueled vehicles (about 9:1) to values exceeding 13:1. This alone will increase engine efficiency by about 10 percent.

Methanol can be used in a combustion system which operates lean much of the time to provide attendant benefits in fuel efficiency. For lean operation, methanol's characteristics are superior to gasoline, resulting in efficiency gains in the 15 percent range.

The combustion of methanol produces a slight increase in engine power even if nothing is done to increase the compression ratio, because the post-combustion pressure is higher with methanol. This effect alone is about 6 percent. Also, the combustion of methanol results in less heat transfer losses to the engine's cooling system which is another efficiency plus.

There is a synergistic effect when an optimized methanol-fueled engine and vehicle are considered. The higher compression ratio possible and the higher post-combustion pressure both combine to make the engine more powerful for a given engine size. This benefit could be taken as higher performance in the form of increased power. However, if the performance target remains constant compared to gasoline, the engine size can be reduced. This results in even better fuel efficiency since idle fuel consumption is reduced. A smaller engine can be lighter and this means a lighter overall vehicle due to the lighter engine and corresponding lighter weight vehicle structure. Both weight reductions also yield improved vehicle fuel efficiency.

Even without considering the synergistic effects, substantial improvements will be achieved. A 30 percent increase in vehicle efficiency seems a reasonable assumption and is within the range of the values estimated by Chevron. (See attached Chevron Figure 4-1 from reference number 5 below.) The degree to which manufacturers choose to optimize fuel efficiency rather than performance will depend on such factors as fuel economy standards, fuel prices, and the perceived relative marketability of "power" versus "fuel economy".

EPA, in its Ann Arbor laboratory, has tested prototype vehicles powered by methanol-fueled engines which employ some of the characteristics just described. Vehicles from two different manufacturers have been evaluated. Since the M100-fueled vehicles did not have an exact weight and performance match in the gasoline-fueled vehicle base, the data were adjusted to estimate matched results.

	Efficiency Benefit of M100 Over Gasoline (percent)	
Manufacturer	Before Adjustment	After Adjustment
N	47	36
T	20	26

These values from vehicles that are not fully optimized span the 30 percent estimate being used.

The following references provide useful additional information on this topic:

1. K.H. Hellman, "Adjusting MPG for Constant Performance," note to Charles L. Gray, Jr., U.S. EPA, May 1986.

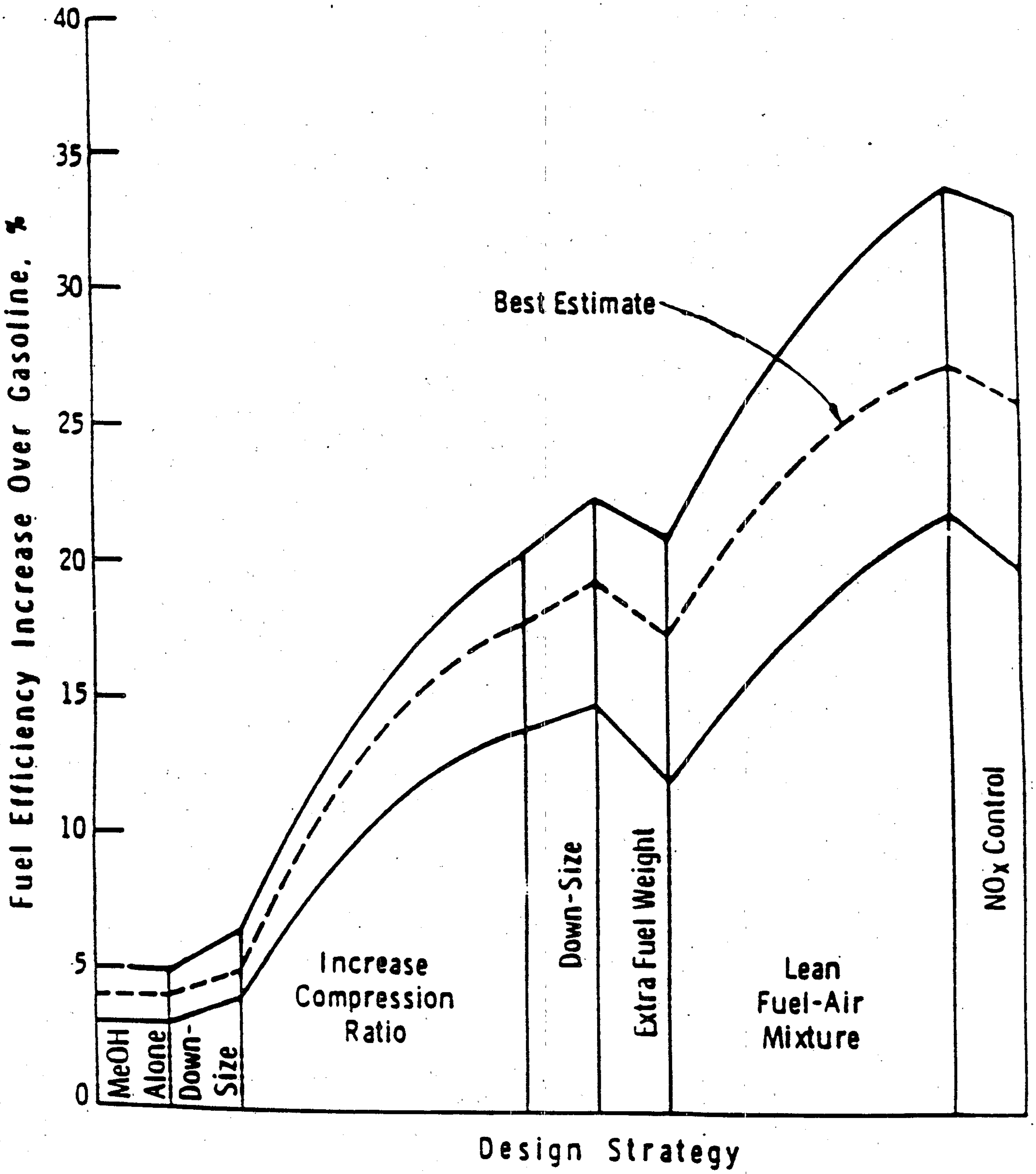
2. K. Katoh, et al., "Development of Methanol Lean Burn System," SAE Paper 860247, February 1986.

3. G.K. Piotrowski and J.D. Murrell, "Phase I Testing of Toyota Lean Combustion System (Methanol)," Report No. EPA/AA/CTAB/87-02, January 1987.

4. "Preliminary Test Results from the Nissan Sentra Methanol-Fueled Vehicle," memorandum from Karl H. Hellman to Charles L. Gray, Jr., U.S. EPA, July 6, 1989.

5. "The Outlook for Use of Methanol as a Transportation Fuel," prepared for the National Science Foundation Workshop on Automotive Use of Methanol-Based Fuels, Chevron U.S.A., January 1985.

FIGURE 4-1



Note: Figure taken from "The Outlook for Use of Methanol as a Transportation Fuel," Chevron U.S.A., Inc., January 1985.

What Would Be The Gasoline-Equivalent Methanol Retail Price?

The projected gasoline-equivalent methanol retail price is simply the methanol port price plus the added costs of distribution, service station markup, and taxes, multiplied by a ratio accounting for the number of gallons needed for a methanol vehicle to travel the same distance as a gasoline vehicle on a gallon of gasoline. Because methanol has one-half of the energy of a gallon of gasoline, if methanol (M100) vehicles had only equal energy efficiency then the ratio is 2.0. An M85 vehicle with 5 percent improved efficiency would have a ratio of 1.67. At 30 percent better energy efficiency, appropriate for dedicated and optimized M100 vehicles, then the ratio is 1.54 (2 divided by 1.3). Thus, as shown in the following table, the projected gasoline-equivalent methanol retail price would be $1.14 to $1.24 for an M85 vehicle with 5 percent better energy efficiency at current methanol prices, and $1.10 to $1.14 per gallon for equal efficiency and $0.85 to $0.88 per gallon for 30 percent better efficiency for M100 vehicles at projected future methanol prices.

Gasoline-Equivalent Methanol Retail Price
(cents per gallon)

	M100 Equal Efficiency	Current M85 5% Better Efficiency	Future M100 30% Better Efficiency
Methanol Port Price	35	40-45	35
Gasoline Blending for M85	0	4-5	0
Distribution, Markup, and Taxes	20-22	23-25	20-22
Total Methanol Retail Price	55-57	68-74	55-57
Gasoline-Equivalent Ratio	2.0	1.67	1.54
Total Gasoline-Equivalent Methanol Retail Price	110-114	114-124	85-88

Attachment 3

Sensitivity Analysis of Methanol and Gasoline Price Comparison

Future crude oil and natural gas prices will obviously affect the relative prices of gasoline and methanol, however predicting crude oil and gas prices is rather difficult. Future crude oil price increases will likely cause domestic natural gas prices to increase as well. Remote natural gas prices will likely increase too, but at a lesser rate than crude oil (based on the fact that the remote gas has no other competitive market and it is not controlled by a cartel). Also important is the capital recovery rate (CRR) used in determining future fuel prices, as it relates to both future methanol and gasoline prices. Methanol vehicle efficiency improvements will also have an impact on methanol's ability to compete. After analyzing each of these parameters individually, the interrelationship among them will be defined, allowing consideration of the circumstances under which methanol price "breaks-even" with that of gasoline.

Cost of Fuel Methanol Production

Capital Recovery Rate

As discussed earlier, EPA has used a real after-tax return on investment of 10 percent in this analysis. While the "projected" return on investment used as a criterion in corporate spending decisions is often higher than this, the fact remains that capital investments are being made in the motor fuel sector where a real after-tax return on investment of 10 percent is realistically expected. Thus, in a stable fuel methanol market situation, the CRR for a methanol facility and a refinery should be about the same.

There has been some concern raised over whether investment in a methanol plant would be riskier than investment in a gasoline refinery, thus requiring a higher return on investment. Under a stable, secure market this would not likely be the case. As methanol demand grows, potential producers will compete to supply the market, subject to risks similar to those faced by the petroleum industry. The perception that future gasoline refineries will be built in safe domestic areas while methanol plants will be built overseas is also unfounded. The new refineries being built are located in the Middle East and South America, not in the U.S. Required returns on investment in these areas will not necessarily be higher than in the U.S. either. In deriving

Middle East gas costs for the oil company-sponsored SRI report, Jensen Associates, Inc. used a capital recovery rate of 15 percent in analyzing a gas production plant located in Qatar, even lower than the 16.2 percent used in this analysis.(1)

Further, there are some risks currently facing the petroleum refining industry that would not be faced by the fuel methanol industry. The potential for environmental regulation of gasoline composition creates uncertainty for refinery investors. For instance, regulations requiring the removal of aromatics from gasoline would make reforming for octane unprofitable. Faced with this potential, investing in a new reformer (a major cost item in a new refinery) is risky. The potential for other gasoline regulations pose additional risk. The possibility of more stringent fuel economy standards also poses some risk of future reductions in gasoline demand. Thus, the idea that gasoline refining is comparatively a low-risk, stable operation may not hold true for the future.

As discussed in the analysis of EPA's projected methanol cost presented earlier, when a CRR of 16.2 percent is applied to the estimated methanol plant investments values, annual investment related costs ranging from $143 million to $249 million (12.4-21.6¢/gal) result. These are shown for each of the six sites evaluated in the Bechtel study in Table 1. While, as described above, EPA believes a CRR of 16.2 is most appropriate for this analysis, it is instructive to consider the effect that other CRRs might have on methanol price. Thus, Table 1 also shows the sensitivity of the methanol price as a function of CRR. One lower CRR of 10 percent, typical of utility investment, and two higher CRRs, 20 percent and 30 percent, corresponding to high-risk/high-profit potential investments are shown. The 20 percent CRR increases the methanol production cost by only 3-5¢/gal at the various sites, and the 30 percent CRR increases the methanol costs 11-18¢. Clearly, programs designed to minimize the risk to the investor are critical to assuring the availability of low priced methanol.

Natural Gas Feedstock Price

By far the most sensitive and controversial factor influencing methanol cost is the projected natural gas feedstock price. With current technology plants, the price of methanol is increased by about 10¢/gal for every $1 per million Btu ($1/MMBtu) increase in the price of natural gas. The price at which natural gas is available, in turn, is dependent on

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(1) "Natural Gas Supply, Demand, and Price," James T. Jensen, Jensen Associates, Inc., February 1989

Table 1

Cost of Fuel Methanol Delivered to Los Angeles

Location	Trinidad	Mid East	Australia	Canada	US Gulf	Alaska
Annual Natural Gas Consumption (bcf)	109.6	109.6	109.6	109.6	109.6	109.6
Annual Methanol Production (million gal)	1151	1151	1151	1151	1151	1151
Total Capital Cost (Million 1988 $)	985	1088	1537	926	883	1498
Capital Recovery Cost (¢/gal)						
-16.2% CRR	13.9	15.3	21.6	13.0	12.4	21.1
-10% CRR	8.6	9.5	13.4	8.0	7.7	13.0
-20% CRR	17.1	18.9	26.7	16.1	15.3	26.0
-30% CRR	25.7	28.4	40.1	24.1	23.0	39.0
Nongas Operating Cost (¢/gal)	5.9	7.1	9.1	5.4	5.6	9.4
Transport Cost (¢/gal)	5.0	5.0	4.0	8.0	0.0*	8.0*

* Bechtel estimated costs of 9¢ and 52¢/gal from the Gulf Coast and Alaska sites, respectively.

the price of competing energy sources (crude oil, coal, etc.), the existence of a viable market for the gas at the particular location, and the cost of collecting and transporting the gas to that market. In highly developed areas, such as the U.S. Gulf Coast, an extensive gas pipeline infrastructure exists to supply domestic demand, therefore linking the value of natural gas to other premium energy prices. In remote locations, such as Prudhoe Bay, however, no market for natural gas exists, nor is one likely to develop in the near future, and thus the natural gas has little market value. The price at which natural gas could be supplied to a methanol plant at such a location would thus be minimal, reflecting principally the costs of collection and transport to the facility. In other developing countries, it is difficult to predict the rate at which alternative markets for natural gas will develop, thus adding complexity to the issue.

As presented earlier, because of the widespread availability of vast quantities of currently unmarketable gas, it seems reasonable to expect that it will be possible to identify low cost natural gas in sufficient quantities to supply methanol production facilities. For example, the report prepared by SRI estimated that natural gas could be available to the Prudhoe Bay, Alaska site at under $0.50/MMBtu over the next 20 years.(1) In numerous other locations, given the vast quantity of natural gas which is currently vented, flared, and re-injected, it seems likely that gas can be supplied at prices ranging from $0.50-1.00/MMBtu, thus contributing 5-10¢/gal to the price of methanol at those sites. In developed areas such as the U.S., higher natural gas prices (greater than $1.50/MMBtu or so) may prohibit the competitive production of fuel grade methanol. As petroleum prices rise in the future, it seems reasonable to expect upward pressures on all natural gas. However, considering the diversity of supply of natural gas and the absence of competing uses of the gas at most locations, the energy price rise of remote natural gas should be slower than that of petroleum.

In summary, natural gas prices of $0.50-1.00 MMBtu will be likely in remote areas resulting in gas related costs of 5-10¢/gal of methanol. As will be seen later in this attachment, however, even with substantially higher gas prices, methanol can compete economically with gasoline.

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(1) "The Economics of Alternative Fuels and Conventional Fuels," SRI International, presented to the Economics Board on Air Quality and Fuels, February 1989.

Cost of Gasoline Production

Based on contractor estimates and published construction data, a new 100,000 barrel per day refinery (roughly the size of an average U.S. refinery) would cost about $1 billion to construct.(1,2) Using an annual capital recovery factor of 16.2 percent, (based on a 10 percent cost of capital and a 15 year economic life typical of the U.S. refining industry), this translates into a daily capital-related charge of $440,000. For the range of CRR's used to assess methanol production as shown in Table 1 (10-30%), daily capital related costs at a petroleum refinery would range from $270-820,000 per day.

Based on refinery modeling performed by Bonner and Moore (a highly respected petroleum industry contractor), daily operating costs (feedstocks and utilities) for such a refinery were calculated to be approximately $2.3 million (assuming $20/bbl crude oil).(3) These costs were allocated over the entire product slate, proportional to total expected revenues from each product. Capital related charges were appropriately allocated only to "capital intensive" products (i.e., gasoline, No. 2 distillate, kerosene, and aviation fuel). Bonner and Moore also project that six percent of capital per year is spent for local taxes, maintenance, and insurance. This cost was also allocated to gasoline and distillate product sales.

Using this cost and allocation scheme, the gate price of gasoline can be projected for various crude oil prices. For instance, at a crude oil price of $20/bbl (the cost of crude oil recently), the calculated gasoline cost is 68.6¢/gal, (63.8-79.2¢/gal for CRR's ranging from 10-30%). At a crude oil price of $35/bbl, feedstock and utility costs increase, raising the calculated gasoline cost to 106.7¢/gal (101.9-117.3¢/gal). This relationship between gasoline price and crude oil cost can be used to estimate gasoline prices under various crude oil price scenarios. Table 2 shows a pump price comparison for gasoline and methanol under two different crude oil price scenarios, including vehicle efficiency considerations.

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(1) Debra A. Gwyn, "Worldwide Construction," Oil & Gas Journal, April 10, 1989.
(2) Personal Communication with Bonner and Moore Management Science personnel, May 3, 1989.
(3) "Assessment of Impacts on the Refining and Natural Gas Liquids Industries of Summer Gasoline Vapor Pressure Control," prepared for U.S. EPA by Bonner & Moore Management Science, August 24, 1987.

Table 2

Total Pump Price Comparison

	Low Crude ($20/bbl)		High Crude ($35/bbl)	
	Gasoline	Methanol	Gasoline	Methanol
Refinery/Port Price	68.6	35	106.7	35
Long Range and Local Distribution*	6(3)	3	6(3)	3
Service Station Markup	9	5-7	9	5-7
All Taxes	24	12	24	12
Subtotal Distribution	39(36)	20-22	39(36)	20-22
Total Pump Price	107.6 (104.6)	55-57	145.7 (142.7)	55-57
Per Gallon Gasoline Equivalent:				
- 5% Methanol Efficiency Improvement	104.6	105-109	142.7	105-109
- 30% Methanol Efficiency Improvement	104.6	85-88	142.7	85-88

* Long-range distribution for gasoline made from a new refinery (likely located or foreign soil) would be similar to those of methanol (3¢/gal) since shipping routes would be similar for either product.

Methanol/Gasoline Comparison

Each of these factors impacts the relative price at which methanol and gasoline will be available. In order to more clearly understand the relationship between these variables, a "break-even" natural gas price (the natural gas price at which gasoline and methanol have the same cost per mile traveled) has been defined in terms of crude oil price, capital recovery rate (CRR), and vehicle efficiency, using the capital investment, operating, and transport costs defined by Bechtel for the Trinidad site.(1,2) For the CRR (16.2 percent) used in this analysis, and assuming a 30 percent vehicle efficiency improvement a break even natural gas price of $2.33/MMBtu at a crude oil price of $20/bbl is calculated. Table 3 shows the break-even natural gas price for various CRR's, crude oil prices, and vehicle efficiencies.

As can be seen from Table 3, even with no efficiency improvement, at current oil prices the break-even natural gas price is $0.69/MMBtu. With a 30 percent improved efficiency methanol vehicle, as long as natural gas prices do not exceed $2.33/MMBtu (Trinidad location), methanol will cost less than gasoline ($20/bbl crude). With $35/bbl crude, natural gas prices could rise as high as $4.85/MMBtu. As can be seen, the assumed CRR has only a minor effect.

This relationship between break-even natural gas price, crude oil price, and vehicle efficiency is graphically illustrated in Figure 1 for a CRR of 16.2 percent. Also shown is an "LNG netback" for Trinidad, based on DOE's U.S. wellhead gas price projections and LNG production and transport costs.(3) Also shown is a "Likely" remote gas price, assumed

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(1) The break-even natural gas price can be expressed mathematically as shown in Appendix A.

(2) "California Fuel Methanol Cost Study," prepared by Bechtel, Inc., for Chevron U.S.A., Inc., Amoco Oil Company, ARCO Products Company, California Energy Commission, Canadian Oxygenated Fuels Association, Electric Power Research Institute, Mobil Research and Development Corporation, South Coast Air Quality Management District, Texaco Refining and Marketing, Inc., Union Oil Company of California, January 1989.

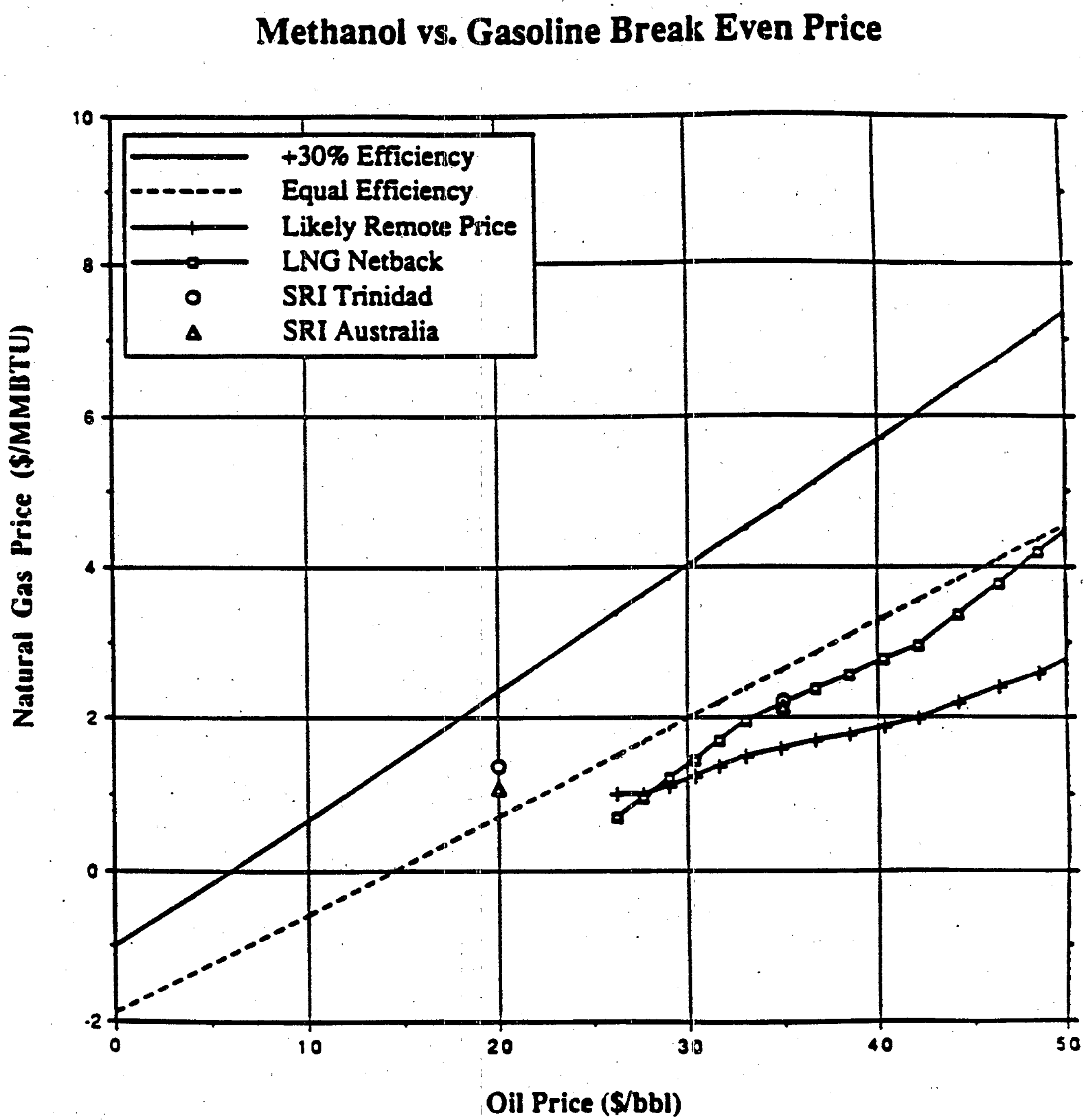
(3) "Long Range Energy Projections to 2000," U.S. DOE, Office of Policy, Planning, and Analysis, DOE/PE-0082, July 1988.

Table 3

Break-Even Natural Gas Price as a Function of Crude Oil Price, CRR, and Vehicle Efficiency

Crude Oil ($/bbl)	Capital Recovery Rate (%)	Methanol Efficiency Improvement (%)	Break-Even Natural Gas Price ($/MMBtu)
20	16.2	0	0.69
20	16.2	5	0.97
20	16.2	30	2.33
20	20	30	2.19
20	30	30	1.83
35	16.2	30	4.85
35	20	30	4.71
35	30	30	4.34

FIGURE 1



Methanol vs. Gasoline Break Even Price
+30% Efficiency
Equal Efficiency
Likely Remote Price
LNG Netback
SRI Trinidad
SRI Australia
Natural Gas Price ($/MMBTU)
10
8
6
4
2
0
-2
0
10
20
30
40
50
Oil Price ($/bbl)

to be the midpoint between the LNG netback and the cost of service for the Trinidad location, as estimated by the gas price contractor used in the SRI International study.(1) As the figure shows, remote gas prices are projected to be significantly less than the break-even price, even those estimated by the recent SRI study.(2)

For a more thorough explanation of the fuel price estimates and assumptions employed in this study, refer to the following documents:

1. "Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector, Technical Report Two: Executive Summary--Methanol and LNG Production and Transportation Costs," Office of Policy, Planning and Analysis, U.S. DOE, May 1989.

2. "The Economics of Alternative Fuels and Conventional Fuels," SRI International, prepared for California oil companies, February 2, 1989.

3. "Australia as a Potential Source of Methanol for the California Clean Fuels Program," BHP Petroleum FTY LTD, January 1989.

4. K. Mansfield, ICI Chemicals and Polymers Limited, letter to Charles L. Gray, Jr., U.S. EPA, May 25, 1989.

5. "California Fuel Methanol Cost Study," prepared by Bechtel, Inc., for Chevron U.S.A., Inc., Amoco Oil Company, ARCO Products Company, California Energy Commission, Canadian Oxygenated Fuels Association, Electric Power Research Institute, Mobil Research and Development Corporation, South Coast Air Quality Management District, Texaco Refining and Marketing, Inc., Union Oil Company of California, January 1989.

6. "Assessment of Impacts on the Refining and Natural Gas Liquids Industries of Summer Gasoline Vapor Pressure Control," prepared for U.S. EPA by Bonner & Moore Management Science, August 24, 1987.

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(1) "Natural Gas Supply, Demand, and Price," James T. Jensen, Jensen Associates, Inc., February 1989.

(2) "The Economics of Alternative Fuels and Conventional Fuels," SRI International, prepared for California oil companies, February 2, 1989.

7. "Butane Suppliers: An Industry Profile and Analysis of the Impacts of Decreased Market Prices Caused by Gasoline Volatility Control," prepared by Jack Faucett Associates for U.S. EPA, February 1988.

8. Debra A. Gwyn, "Worldwide Construction," Oil & Gas Journal, April 10, 1989.

9. "Natural Gas Supply, Demand, and Price," James T. Jensen, Jensen Associates, Inc., February 1989.

10. Octane Week, Volume IV, Number 4, June 5, 1989.

11. "Cost & Availability of Low Emission Motor Vehicles and Fuels," AB 234 Report, California Energy Commission, Draft, April 1989.

12. "Discussion Review of Critical Cost Assumptions for Methanol as Presented at the AB 234 Workshop on February 1-2, 1989," Acurex Corporation, February 16, 1989.

13. "Statement by ICI on the Proposed SCAQMD Phase Out Policy," letter to Mr. Paul Wuebeen, SCAQMD from G. D. Short, ICI Products, December 6, 1988.

14. Letter from Charles L. Gray, Jr., U.S. EPA to Mr. Robert Friedman, Office of Technology Assessment, June 8, 1989.

15. "Methanol Manufacturing Plant Financing," William E. Stevenson, Bechtel Financing Services, Inc., February 1, 1989.

16. "Alternate Fuels Supply Issues," Mike Lawrence, Jack Faucett Associates, slides presented at SAE Government/Industry Meeting, May 1989.

17. Letter to Ms. Jananne Sharpless, Secretary of Environmental Affairs, State of California from R. Colledge, Canadian Oxgenated Fuels Association, April 3, 1989.

18. Letter to Charles L. Gray, Jr., U.S. EPA from J.J. Hennessey, Vice President and General Manager, Alberta Gas Chemicals, Inc., March 22, 1989.

19. Letter to Honorable Jananne Sharpless, Secretary of Environmental Affairs, State of California from Peter J. Booras, President, Yankee Energy Corporation, January 9, 1989.

20. Letter To Jeffrey A. Alson, U.S. EPA from Chris Grant, Alberta Gas Chemicals, Incorporated, April 28, 1989.

21. Letter to Charles L. Gray, Jr., U.S. EPA, from R. D. Morris, Hoechst Celanese, April 27, 1989.

22. Richard L. Klimisch, General Motors Corporation, Testimony before U.S. Congress, House of Representatives, Committee on Energy and Commerce, Subcommittee on Energy and Power, June 17, 1987.

23. "Alcohol Outlook," Information Resources, Inc., July 1989.

24. <u>International Energy Annual, 1987</u>, DOE/EIA-0219(87), Energy Information Administration, 1987.

25. <u>Natural Gas Annual, 1987 - Volume II</u>, DOE/EIA-0131(87)/2, Energy Information Administration, 1987.

26. "Distribution of Methanol for Motor Vehicle Use in the California South Cast Air Basin," Energy and Environmental Analysis, Inc., prepared for U.S. EPA, September 1986.

27. "Long Range Energy Projections to 2000," U.S. DOE, Office of Policy, Planning, and Analysis, DOE/PE-0082, July 1988.

28. "Alcohol Week," July 10, 1989.

29. "Letter to Charles L. Gray, Jr., U.S. EPA from R.D. Morris, Hoechst Celanese Corporation, June 2, 1989.

30. Letter to Charles L. Gray, Jr., U.S. EPA, from George E. Crow, Manager, Fuels Planning, Sun Refining and Marketing Company, May 31, 1989.

31. "Capital Servicing Costs of Fuel Methanol Plants," William E. Stevenson, Bechtel Financing Services, Inc., May 3, 1989.

32. Responses by Helen Petrauskas, Ford Motor Company, and Robert Frotsch, General Motors Corporation, to questions at the Joint Hearing by the Subcommittees on Fossil and Synthetic Fuels and Energy Conservation and Power, April 25, 1984.

33. "Conversion of Offshore Natural Gas to Methanol," Phase I Report, Federal Highway Administration, U.S. Department of Transportation, Contract: DTFH-61-85-C-0076, Yankee Energy Corporation, May 1987.

34. Letter to Charles L. Gray, Jr., U.S. EPA, from John Meyers, President, Fuel Methanol of America, Inc., January 4, 1989.

35. Letter to Charles L. Gray, Jr., U.S. EPA, from Y. Mizukami, General Manager, Energy and Chemical Project Manager, Marubeni Corporation, December 27, 1988.

Appendix A

Derivation of "Break-even" Natural Gas Price

Methanol Port Cost (from Trinidad)

$$M_{port} = 5.9 + 5 + 0.8558\ (CRR) + 9.8(N)$$
$$= 10.9 + 0.8558\ (CCR) + 9.8\ (N)$$

M_{port} = Methanol Port Price (¢/gal)
CRR = Annual Capital Recovery Rate (%)
N = Natural Gas Feedstock Price

Methanol Pump Cost

$$M_{pump} = 10.9 + 0.8558\ (CRR) + 9.8(N) + 22$$
$$= 32.9 + 0.8558\ (CCR) + 9.8\ (N)$$

Methanol Pump Cost (per gallon gasoline equivalent)

$$M_g = M_{pump}\ \frac{2.00}{(1 + \frac{E}{100})}$$

M_g = Methanol Pump Cost (Gasoline Equivalent)

E = Efficiency Improvement of Methanol Vehicle (%)

Gasoline Pump Cost

$$G = 2.54(C) + 5.323 + 0.7703\ (CRR) + 39$$
$$= 2.54(C) + 0.7703\ (CRR) + 44.323$$

G = Gasoline Pump Cost (¢/gal)
C = Crude Oil ($/bbl)

Break Even Price

$$N=(1+\frac{E}{100})\ x\ (2.2506 + 0.129C + 0.0391\ CRR) - (0.0873\ CRR + 3.357)$$

Where,

N = Break-even Natural Gas Price ($/MMBtu)
E = Methanol Vehicle Efficiency Improvement (percent)
C = Crude Oil Price ($/bbl)
CRR = Annual Capital Recovery Rate (percent)

Attachment 4

What Is the Cost Difference Likely To Be Between A Methanol Vehicle and Its Conventional Fuel Counterpart?

The most significant environmental benefits available with methanol fuel would be with the use of optimized, dedicated M100 vehicles. Several propotype dedicated M100 vehicles have been evaluated, but certain features of the optimized M100 vehicle continue to be under development, in particular, the method of starting under cold temperatures. Several methods of cold starting have been demonstrated, including propane assist and direct cylinder fuel injection. However, the optimum resolution of this and other issues will likely be identified in the next several years.

In projecting the incremental cost of a dedicated methanol vehicle relative to a gasoline vehicle, a two-sided approach was followed. First, the estimates that are supported by the vehicle manufacturers were obtained and then an independent analysis was performed. From Congressional testimony in 1984, both Ford and General Motors stated that in volumes of 100,000 or more the cost of a dedicated methanol vehicle would be no more than that of a comparable gasoline vehicle.(1)

The second step in the process was to perform a cost tradeoff analysis between the methanol vehicle and its gasoline counterpart. Use of M100 in an optimized engine concept will allow use of a smaller, lighter engine which delivers the same power as the engine it replaces. This has two important implications. First, in addition to the weight saved in the engine, use of a lighter engine has a compounding effect on the vehicle. Portions of the body structure and the suspension can be made lighter, especially if the engine/vehicle design is done as an entire system, such as is the case for a new engine/vehicle combination. Once this design process is complete, the resulting vehicle will have better performance since it will have equivalent power and weigh less than the vehicle it replaces. This leads to the second implication. Even further reductions in weight are possible if the engine is resized for equivalent performance, since a smaller engine can be used. Use of a smaller engine of lower power will allow powertrain weight and cost savings because the power transmitted will be reduced.

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(1) Responses by Helen Petrauskas, Ford Motor Company, and Robert Frotsch, General Motors Corporation, to questions at the Joint Hearing by the Subcommittees on Fossil and Synthetic Fuels and Energy Conservation and Power, April 25, 1984.

Further cost savings in the emission control system due to reduced engine size are possible. Most emission control systems use a certain ratio of catalyst volume to engine displacement. With a smaller engine, a smaller catalytic converter could be used, with no loss in emission control capability.

Methanol's combustion properties are such that less heat is rejected into the engine's cooling system. That fact, coupled with the cool exhaust typical of highly efficient M100 combustion, leads to more savings. In order to ensure that the catalyst will light-off quickly enough, the M100-fueled engine will have to increase the sensible heat in the exhaust. This will require exhaust port insulation, which will provide the appropriate exhaust conditions for good emission control. It is then not necessary to reject as much heat in the vehicle's cooling system. It will clearly be possible to reduce the size of the conventional radiator substantially and it may even be possible to eliminate the conventional radiator, fan, and controls completely and rely on only the heater core for engine heat rejection.

Methanol's volatility characteristics make it an excellent fuel as far as evaporative emissions are concerned. The combination of low volatility and high specific heat make the evaporative emissions characteristics of M100 so good that much of the cost of the evaporative emission control systems can be saved.

In addition to the cost savings outlined above, possible cost increases must be considered. Considerations of fuel system modifications for M100 compatibility might lead to cost increases; however, the fact that fuel systems are now being made tolerant of oxygenated fuel blends might make this less so. All vehicles will already be tolerant of these blends when optimized M100 vehicles are introduced and the changes already made may be sufficient for methanol, since intermediate level oxygenated blends are in some ways more of a challenge to the fuel system than M100. Therefore, fuel compatibility should not result in a significant cost increase.

The more sophisticated fuel injection system that will be required for satisfactory cold start performance with an advanced optimized M100 engine is expected to result in a cost increase over the fuel metering system on the engine it replaces, but the systems currently under consideration are low cost designs. The fuel tank for a dedicated methanol vehicle will also be larger and more expensive and may involve modifications such as a flame arrestor or bladder for safety reasons. Additionally, formaldehyde controls may lead to more expensive catalytic converters.

In summary, there are several areas in which cost savings over conventional vehicles are possible and several in which cost increases will be possible. While much uncertainty still exists regarding the relative costs of future gasoline and M100 vehicles, this report assumes a base case scenario in which the savings and the increases will net out to zero, and that there will be no cost difference between future optimized M100 engine/vehicle systems and the vehicles they replace.

In determining the incremental costs of FFVs, several considerations must be taken into account. First, since FFVs must be capable of operating on methanol, they must incorporate those modifications necessary for methanol combustion discussed above which can increase vehicle cost. Yet, because FFVs must also operate well on gasoline, they cannot incorporate any of the changes discussed above which can reduce dedicated methanol vehicle cost. The fuel tank for an FFV would have to be larger than those of a dedicated methanol vehicle in order to provide equivalent range. This could be somewhat more problematic because such vehicles will sometimes carry the more volatile gasoline fuel, and there will be no offsetting weight reductions. One component necessary for an FFV that neither a gasoline nor a methanol vehicle must have is a fuel sensor. Since fuel sensors used by both General Motors and Ford in their FFVs have never been mass produced, the cost impact of doing so is very difficult to assess. Given this extra componentry required and the inability to take advantage of the cost savings described above for dedicated methanol vehicles, EPA is relying on Ford cost estimates of an extra $200 to $400 per vehicle to produce an FFV at high volumes compared to a gasoline vehicle. Hence, a value of $300 per vehicle is used as the incremental cost of FFVs for purposes of projecting the total costs of the neat fuels program.

Attachment 5

Environmental Implications of Methanol

Urban Ozone Levels

The primary environmental benefit of methanol will be significant improvements in ozone levels in the most seriously polluted areas of the country. Projected hydrocarbon reductions have been computed for each of the nine most serious ozone non-attainment cities. For this analysis, it is assumed that methanol flexible fuel vehicles (FFVs) will be sold for the first five years (1995-1999), while sales thereafter will be dedicated M100 vehicles. However, the results apply to any clean fueled vehicles that meet the same emissions performance targets.

EPA's projection that methanol vehicles will yield lower "ozone-producing potential" or "gasoline VOC-equivalent emissions" involves two primary inputs: emission factors for the various organic compounds emitted by gasoline and methanol vehicles and reactivity factors which account for the fact that different organic compounds have various propensities for yielding ozone. Table 1 gives projected in-use organic emission factors (excluding methane which is considered to be nonreactive for purposes of urban ozone formation) for current and improved gasoline vehicles, methanol FFVs that operate on M85, and optimized, dedicated M100 vehicles. The gasoline vehicle emissions values in Table 1 are from the EPA MOBILE4 computer emissions model. Since MOBILE4 does not include formaldehyde emissions, gasoline vehicle formaldehyde emission factors were derived assuming that formaldehyde constituted 1 percent of the total exhaust HC level based on EPA test data involving in-use gasoline vehicles.(1,2,3,4,5,6) The emissions of a fleet of gasoline vehicles meeting the new requirements of the Clean Air Act proposal were estimated by making special changes to the MOBILE4 program to reflect the proposed requirements, including that of a more stringent inspection and maintenance program than assumed for current gasoline vehicles. All of the estimates in Table 1 are for a 71°F to 95°F ozone season day.

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(1) Volatile Organic Compound Emissions from 46 In-Use Passenger Cars, John E. Sigsby, Jr. et al., U.S. Environmental Protection Agency, Environ. Sci. Technol., Volume 21, 1987.

(2) Unregulated Exhaust Emissions from Non-Catalyst Baseline Cars Under Malfunction Conditions, Charles Urban, Southwest Research Institute, Report EPA-460/3-81-020, May 1981.

(3) Regulated and Unregulated Exhaust Emissions from Malfunctioning Non-Catalyst and Oxidation Catalyst Gasoline Automobiles, Charles Urban, Southwest Research Institute, Report EPA-460/3-80-003, January 1980.

(4) Regulated and Unregulated Exhaust Emissions from Malfunctioning Three-Way Catalyst Gasoline Automobiles, Charles Urban, Southwest Research Institute, Report EPA-460/3-80-004, January 1980.

(5) Characterization of Exhaust Emissions from High Mileage Catalyst-Equipped Automobiles, Lawrence R. Smith, Southwest Research Institute, Report EPA-460/3-81-024, September 1981.

(6) Mobile Source Emissions of Formaldehyde and Other Aldehydes, Penny M. Carey, U.S. Environmental Protection Agency, Report EPA/AA/CTAB/PA/81-11, May 1981.

Table 1

Projected In-Use Organic Emissions for Gasoline and Methanol Vehicles
(grams per mile)

Type of Emission	Gasoline Vehicles, Current Standards (9.0 psi)			Gasoline Vehicles Under Standards Proposed by Pres. Bush (9.0 psi)			Interim Technology FFV's on M85 in 1995 - 1999			FFV's optimized for M85			Vehicles Optimized for M100		
	NMHC	MeOH	HCOH	NMHC	MeOH	HCOH	NMHC	MeOH	HCOH	NMHC	MeOH	HCOH	NMHC	MeOH	HCOH
Exhaust	.70	0	.007	.53	0	.005	.190	.700	.060	.150	.500	.035	.050	.500	.015
Hot Soak/ Diurnal	.28	0	0	.18	0	0	.058	.122	0	.058	.122	0	0	.030	0
Running Loss	.55	0	0	.16	0	0	.049	.111	0	.049	.111	0	0	.025	0
Refueling	.20	0	0	.07	0	0	.053	.017	0	.053	.017	0	0	.017	0
TOTAL	1.73	0	.007	.94	0	.005	.350	.950	.060	.310	.750	.035	.050	.572	.015

Because there is only a small database of in-use emissions from methanol vehicles, MOBILE4 does not include methanol vehicles and an alternative methodology is necessary for projecting emission factors for methanol vehicles. The FFV M85 exhaust values shown in Table 1 generally reflect the manufacturers' views of what is possible, although there are some differences of opinion among them. With a credits banking program, vehicle manufacturers will have an incentive to make FFV's as clean as practicable. For the evaporative emission components (hot soak/diurnal, running loss, and refueling), the methanol FFV data were assumed to be equal to those of the improved gasoline vehicles on a mass basis (which is reasonable since M85 fuel currently has a volatility similar to 9 RVP gasoline), with the HC-to-methanol ratio based on EPA test data.

There is a very small database with dedicated M100 vehicles, with most of the data generated by EPA test programs. Theoretically, it would be expected that there would be little (exhaust) or no (evaporative) HC in M100 vehicle emissions because of the lack of HC in the fuel, and EPA data support this. EPA has tested several prototype dedicated M100 vehicles with exhaust HC emissions of 0.02 gpm or less and exhaust methanol emissions of 0.40 gpm or less. Averaging these low-mileage data and assuming typical deterioration rates yield the 0.05 and 0.50 gpm emission factors for HC and methanol exhaust emissions given in Table 1. The 0.015 gpm formaldehyde emission factor represents an aggressive yet reasonable goal for optimized M100 vehicles and is equivalent to the long-term standard recently adopted by the California Air Resources Board. EPA has tested two vehicles employing conventional technology, a Volkswagen Rabbit at low mileage and a Toyota Carina at 11,000 miles, that have resulted in formaldehyde levels of approximately 0.010 gpm.(1,2) In addition, testing at EPA with an advanced technology resistively-heated catalytic converter has yielded formaldehyde emissions less than 0.005 gpm. The evaporative emission factors for M100 would be expected to be very low given methanol's extremely low volatility (approximately 5 RVP). This potential for greatly reduced evaporative emissions is supported by a recent test program performed by EPA where organic running loss emissions were measured with both M85 and M100 on the same vehicle (the Toyota Carina) with the gas cap

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(1) "Unregulated Exhaust Emissions from Methanol-Fueled Cars," Lawrence R. Smith, Charles M. Urban, and Thomas M. Baines, Society of Automotive Engineers Paper No. 820967, August 1982.

(2) "Fuel Economy and Emissions of a Toyota T-LCS-M Methanol Prototype Vehicle," J.D. Murrell and G.K. Piotrowski, U.S. EPA, Society of Automotive Engineers Paper No. 871090, May 1987.

removed to simulate a worst-case situation. Over an LA-4 driving cycle the M85 vehicle emitted 3.37 gpm while the M100 vehicle emitted 0.08 gpm, a 98 percent improvement for M100. The projected evaporative emission factors for optimized M100 vehicles in Table 1 reflect the very low evaporative emission levels that would be expected from all M100 vehicles, even considering worst-case situations where major emission control tampering has occurred.

By summing the various emission components in Table 1, it can be seen that methanol FFVs are projected to emit higher overall mass organic emissions, and optimized M100 vehicles lower overall mass organic emissions, than the gasoline vehicles they would be replacing. Both types of methanol vehicles would emit less HC, and more methanol and formaldehyde, than gasoline vehicles.

The second factor to be considered is relative reactivity of the various organic compounds. It has long been recognized that different organic compounds have different photochemical reactivities, i.e., each compound has a unique rate at which it reacts in the complex photochemical reactions that lead to ozone formation. EPA's present exhaust and evaporative HC emission standards assume that the mix of individual HC constituents remains fairly similar from one gasoline vehicle to the next, which is probably a reasonable assumption. But for fuels that are considerably different than gasoline, such as methanol, it is no longer valid to simply assume that organic emissions will have the same overall photochemical reactivities as gasoline vehicle HC emissions.

In order to assess the overall ozone impact of substituting methanol vehicle organics for gasoline vehicle organics, a number of computer simulation studies have been performed.(1,2,3,4) These studies simulated air chemistry and transport within certain urban areas, and accounted for dispersion of pollutants. Based on these studies, EPA has

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(1) Assessment of Emissions from Methanol-Fueled Vehicles: Implications for Ozone Air Quality, R.J. Nichols and J.M. Norbeck, Ford Motor Company, APCA Paper No. 85-38.3, June 1985.
(2) Photochemical Modeling of Methanol-Use Scenarios in Philadelphia, G.Z. Whitten, et al., Systems Applications, Inc., EPA 460/3-86-001, March 1986.
(3) Impact of Methanol Vehicles on Ozone Air Quality, T.Y. Chang, et al., Ford Motor Company, Atmospheric Environment, in press.
(4) "Impact of Methanol on Smog: A Preliminary Estimate," Gary Z. Whitten, Systems Applications, Inc. Report for ARCO Petroleum Products Company, February 1983.

developed a model that provides reactivity factors for methanol and formaldehyde relative to typical HC from gasoline vehicles.(1)* Based on this model, the average reactivity factors on a carbon basis are projected to be 0.43 for methanol and 4.8 for formaldehyde. That is, on an equivalent-carbon basis, the methanol molecule has only 43 percent of the potential to form ozone as the typical gasoline HC molecule, while the formaldehyde molecule has a 4.8 times higher potential. On a gram per mile basis, the reactivity factors are 0.19 for methanol and 2.2 for formaldehyde (these compounds have higher mass-to-carbon ratios than typical gasoline HC).

Table 2 utilizes these reactivity factors and the projected emission factors from Table 1 to project the "gasoline VOC-equivalent" emissions for gasoline, methanol FFVs, and optimized M100 vehicles. The data in Table 2 suggest that methanol FFVs would reduce gasoline VOC-equivalent emissions by 30 to 43 percent, while optimized M100 vehicles could reduce gasoline VOC-equivalent emissions by 80 percent. These reductions are relative to gasoline vehicles meeting the new requirements contained in the clean air proposal. It is assumed that methanol FFVs could reduce gasoline vehicle VOC by 30 percent and optimized M100 vehicles would reduce VOC by 80 percent.

Finally, projections had to be made for the fraction of the overall VOC inventory in the affected areas that was due to mobile sources and the fraction of the total mobile source VOC contribution that was due to light-duty vehicles and light-duty trucks.

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(1) Effects of Emission Standards on Methanol Vehicle-Related Ozone, Formaldehyde, and Methanol Exposure, Michael D. Gold and Charles E. Moulis, U.S. Environmental Protection Agency, APCA Paper No. 88-41.4, June 1988.

* The model assumes that the change in peak hourly ozone is linearly proportional to any change in the emission levels of HC, methanol and formaldehyde, as weighted by their respective relative reactivities. The relative reactivity of HC is taken to be 1.0. Modeling results for a total of 20 cities were input into the model to calculate the relative reactivities of methanol and formaldehyde for each city. The results for the 20 cities were averaged to yield the reactivity factors, on a per carbon basis, of 0.43 for methanol and 4.8 for formaldehyde.

Table 2

Projected In-Use Gasoline VOC-Equivalent
Emissions for Gasoline and Methanol Vehicles
(grams per mile)

Vehicle Type	HC	HC Reactivity Factor	Meth	Methanol Reactivity Factor	Form	Formaldehyde Reactivity Factor	Gasoline VOC-Equivalent
Gasoline							
- Current Standards	(1.73	x 1.00) +	(0	x 0.19) +	(.007	x 2.2) =	1.75
- Proposed Standards	(0.94	x 1.00) +	(0	x 0.19) +	(.005	x 2.2) =	0.95
FFVs on M85							
- Readily Feasible	(0.350	x 1.00) +	(0.950	x 0.19) +	(.060	x 2.2) =	0.66
- Optimized	(0.310	x 1.00) +	(0.750	x 0.19) +	(.035	x 2.2) =	0.53
M100							
- Optimized	(0.05	x 1.00) +	(0.572	x 0.19) +	(.015	x 2.2) =	0.19

Assuming that, for the year 2005, mobile sources represent on average only about 15% of the total VOC inventory*, the program described above would yield an average reduction in VOC levels in the 9 metropolitan areas studied of 1.5 percent. In addition, the full VOC benefits are not attained by 2005 since we assume sales of methanol vehicles would not begin until 1995, and because FFVs are projected to be sold for the first five years of the program (1995-1999), only sales thereafter will involve dedicated M100 vehicles. The maximum benefits would accrue by 2015 when dedicated methanol vehicles will have reached a "steady state" in the overall vehicle fleet (assuming the market continued to result in 1,000,000 new dedicated vehicles being sold each year). The average, steady state VOC reduction in 2015 for the nine worst cities would be 3.3 percent.

The projected VOC reductions vary by city, of course, and are given in Table 3 for each of the 9 most serious ozone areas.(1,2) As can be seen, values as high as 2.2 percent are attained in 2005 and as high as 4.7 percent in 2015. It is important to note that these city-specific projections are rough estimates of the VOC reductions that would be achieved; specific projections would be worked out in discussions between EPA and state and local air quality agencies.

While methanol's lower photochemical reactivity is a distinct advantage in terms of urban ozone formation, the question arises as to whether methanol, because of its low reactivity, will cause problems in ozone transport regions by

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* Mobile source emissions currently represent from 30 to 50 percent of an urban area VOC inventory. However, the implementation of more stringent emission standards affecting both motor vehicles and petroleum fuels is expected to significantly reduce the contribution of mobile sources to the total VOC inventory, as vehicles and fuels meeting these standards are phased in. If these programs are not as effective in reducing in use emissions as projected, then mobile source emissions levels would be higher. In the projections described below, city-specific values for the mobile source fraction of total VOC were used, with the average being approximately 15 percent.

(1) "Impact of Methanol Vehicles on Ozone Air Quality," T.Y. Chang, S.J. Rudy, G. Kuntasal, R.A. Gorse, Jr., draft Atmospheric Environment Paper, in press.

(2) "Assessment of Emissions from Methanol-Fueled Vehicles: Implications for Ozone Air Quality," R.J. Nichols and J.M. Norbeck, Air Pollution Control Association Paper 85-38.3, June 1985.

Table 3

Projected City Specific VOC Reductions

Metropolitan Area	2005	Steady State 2015
Los Angeles	1.3	2.9
Houston	0.7	1.6
New York City	2.2	4.7
Milwaukee	1.6	3.4
Baltimore	2.0	4.4
Philadelphia	1.2	2.6
Greater Connecticut	1.9	4.1
Chicago	1.5	3.3
San Diego	1.2	2.6
Typical VOC Reduction	1.5	3.3

reacting downwind. A large modeling study of methanol vehicle use in California's South Coast Air Basin was recently performed by Carnegie Mellon University for the California Air Resources Board.(1) The modeling covered a three-day period (all previous modeling studies examined a single day). The results indicate that the use of methanol vehicles could result in significant reductions in ozone levels for all three days.

No modeling studies of methanol vehicle use have been conducted to address transport episodes of even longer duration. The three-day wind path followed in the CMU study is shorter than some episodes on the East Coast in which a polluted air mass takes days to move from Washington, D.C. to Maine, and possibly drifts over the Atlantic and then returns. With more time available for the ozone reaction, more of the methanol emitted early in the episode will react. However, since the mass of organic carbon from methanol vehicles is less, even the ultimate ozone potential is reduced. Also, methanol can be scrubbed out by rain more so than hydrocarbons. Longer time periods also provide for more dispersion of the methanol emitted early in the episode thus further reducing its concentrations in the cities along the East Coast.

More information on the ozone implications of the clean, alternative fuels program is included in the following references.

1. "Emission Standards For Methanol-Fueled Motor Vehicles and Motor Vehicle Engines," EPA Final Rulemaking, Federal Register Part 86, No. 68, 14426-14613, April 11, 1989.

2. Quantitative Estimate of the Air Quality Impacts of Methanol Fuel Use, Armistead Russell, et al., Carnegie Mellon University, prepared for the California Air Resources Board and the South Coast Air Quality Management District, April 1989.

3. "Notice of Proposed Rulemaking for Methanol-Fueled Vehicles and Motor Vehicle Engines," Federal Register, Vol 51, No. 168, August 29, 1986.

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(1) Quantitative Estimate of the Air Quality Impacts of Methanol Fuel Use, Armistead Russell, et al., Carnegie Mellon University, prepared for the California Air Resources Board and the South Coast Air Quality Management District, April 1989.

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7. "Regulatory Support Document for Proposed Organic Emission Standards and Test Procedures for Methanol Vehicles and Engines," EPA Office of Mobile Sources, July 1986.

8. L.R. Smith, "Characterization of Exhaust Emissions from Alcohol-fueled Vehicles", Southwest Research Institute Report for Coordinating Research Council, CAPE-30-81, October 1984.

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11. "Alcohol Fueled Fleet Test Program - 7th Interim Report," State of California Air Resources Board, MS-85-003, March 1987.

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15. "Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards and Test Procedures for Methanol-Fueled Vehicles and Engines," EPA Report, January 1989.

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18. Proceedings from 7th International Symposium on Alcohol Fuels, Paris, France, October 1986.

19. Proceedings from 8th International Symposium on Alcohol Fuels, Tokyo, Japan, November 1988.

20. Proceedings of the Methanol Health and Safety Workshop, South Coast Air Quality Management District, November 1988.

21. Robert I. Bruetsch, "Emissions, Fuel Economy, and Performance of Light-Duty CNG and Dual-Fuel Vehicles," EPA Office of Mobile Sources Report EPA/AA/CTAB-88-05, June 1988.

22. F. Lipari, R.L. Williams, "Formaldehyde, Methanol, and Hydrocarbon Emissions from Methanol-fueled Cars," Air and Waste Management Association Paper 89-124.3, June 1989.

23. "Influence of Ambient Temperature, Fuel Composition, and Duty Cycle on Exhaust Emissions,", NIPER Final Draft Report to EPA, December 1987.

24. "Alcohol Fueled Fleet Test Program - 8th Interim Report," State of California Air Resources Board, MS-88-05, June 1988.

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26. "Air Quality Benefits of Alternative Fuels," EPA Report for Alternative Fuels Working Group Report of the President's Task Force on Regulatory Relief, July 1987.

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28. "Guidance on Estimating Motor Vehicle Emission Reductions From The Use of Alternative Fuels and Fuel Blends," EPA Office of Mobile Sources Report TSS-PA-87-4, January 29, 1988.

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31. H.G Jeffries, K.G. Sexton, R.M. Kamens, M.S. Holleman, "Outdoor Smog Chamber Experiments: Reactivity of Methanol Exhaust; Part II: Quality Assurance and Data Processing System Description," University of North Carolina Report for EPA Office of Mobile Sources (Report EPA 460/3-85-009b), September 1985.

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36. Joel N. Harris, Armistead G. Russell, Jana B. Milford, "Air Quality Implications of Methanol Fuel Utilization," SAE Paper 881198, August 1988.

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Air Toxics

The use of methanol in motor vehicles will also reduce the air toxics impacts of motor vehicle emissions. The potential reduction in cancer cases in the year 2005 has been estimated earlier. This analysis indicates that methanol would, under the given example, result in about 9 reductions (a reduction of 13 percent) in cancer cases in 2005.

Methanol is not generally considered a toxic pollutant at levels likely to be inhaled from use as a motor vehicle fuel. Available information indicates that methanol is not a carcinogen. The Health Effects Institute, an independent non-profit research organization funded jointly by EPA and the motor vehicle industry, concluded in a May 1987 report that "the weight of available scientific evidence indicates that exposure to methanol vapors is not likely to cause adverse health effects. Health concerns regarding methanol vapors should not prevent government and industry from encouraging the development and use of methanol fuels, assuming that such development and use are otherwise in the public interest."(1) Nevertheless, EPA and HEI are conducting further research in this area, especially with respect to chronic exposure to low levels of methanol.

Table 4 provides a pollutant specific analysis of the air toxics impacts of methanol.(2) A range of total cancer case reductions of 9.3-22.6 is presented. The lower number represents the minimum benefit of the proposed program in the nine affected areas in 2005. Cancer cases are estimated for the year 2005 assuming a 50/50 split of FFVs (utilizing M85 year round) and dedicated vehicles in these areas. The larger number represents the benefit in the nine areas in 2015. Replacement of 30 percent of gasoline vehicles with dedicated methanol vehicles is assumed in the year 2015 in these nine areas. As many as 75 cancer case reductions could be realized, assuming complete replacement of gasoline vehicles with dedicated methanol vehicles in the year 2015 in these nine areas.

The following toxic pollutants were examined: benzene (including exhaust, evaporative, running loss, and refueling benzene), gasoline refueling vapors, exhaust 1,3-butadiene,

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(1) "Automotive Methanol Vapors and Human Health: An Evaluation of Existing Scientific Information and Issues for Future Research," Health Effects Institute Report, May 1987.
(2) Air Toxics Emissions and Health Risks from Mobile Sources, Jonathan M. Adler and Penny M. Carey, U.S. Environmental Protection Agency, APCA Paper No. 89-34A.6, June 1989.

Table 4

Air Toxics Impacts of a Methanol Program

Pollutant/Source	Year 2005 Base Light-Duty Gasoline Motor Vehicle Cancer Cases in Nine Cities*	Per Vehicle Percent Reductions M100	FFVs on M85 (Optimized)	Year 2005 Reductions in Urban Cancer Cases with Proposed Methanol Program**	Year 2015 Reductions in Urban Cancer Cases with Continuation of Methanol Program***
Exhaust Benzene	11.4	97	77	2.0	4.0
Evaporative Benzene	1.5	100	67	0.3	0.6
Running Loss Benzene	1.6	100	69	0.3	0.5
Refueling Benzene	1.9	100	14	0.3	0.7
Gasoline Refueling Vapors (excluding benzene)	11.7	100	14	1.3	4.3
Exhaust 1,3-Butadiene	19.8	99	64	3.2	7.1
Exhaust Gasoline POM	15.4	99	72	2.6	5.6
Direct Formaldehyde	1.3	(+200)	(+600)	(+1.3)	(+1.5)
Indirect Formaldehyde	4.4	80	43	0.6	1.3
Total	69.0			9.3	22.6
Percent Reduction		93%	44%	(13% of Base Risk)	(33% of Base Risk)

* Assumes gasoline vehicles meet standards proposed by the President.

** This program assumes that 20 percent of all passenger cars and light trucks in the nine most serious ozone non-attainment areas in 2005 are methanol vehicles. A 50/50 mix of optimized FFVs (utilizing M85 year round) and dedicated methanol vehicles is assumed.

*** These estimates assume that 30 percent of all passenger cars and light trucks in the nine most serious ozone non-attainment areas in 2015 (or some later year) are dedicated methanol vehicles.

polycyclic organic material (POM) adsorbed onto gasoline-derived particulate matter, and formaldehyde. These pollutants are emitted by gasoline-fueled vehicles and are classified by EPA as either known or probable human carcinogens. The base motor vehicle cancer cases in the year 2005 or 2015 from gasoline-fueled vehicles and light-duty trucks in the nine affected cities were used as a starting point.(1)

To obtain reductions in cancer cases for each pollutant, the base urban cancer cases are multiplied by the per vehicle reductions (expressed as a fraction), and the fraction of the urban gasoline fuel consumption displaced by methanol. As seen in the table, vehicles fueled with neat methanol emit little or no benzene, gasoline refueling vapors, 1,3-butadiene or POM. The virtual elimination of these pollutants with neat methanol use is responsible for most of the cancer reductions. Vehicles fueled with neat methanol also do not emit any diesel particulate; however, since the analysis was only performed for gasoline vehicles, the base cancer cases due to diesel particulate are unaffected and not included in Table 4.

Formaldehyde in ambient air includes both "direct" and "indirect" formaldehyde. Direct formaldehyde is emitted in the exhaust of vehicles, while indirect formaldehyde is formed in the atmosphere from the reactions of various reactive hydrocarbons. As discussed in the Final Rulemaking for methanol-fueled vehicles,(2) indirect formaldehyde is responsible for the majority of the formaldehyde in ambient air, although the relative contribution of direct and indirect formaldehyde is uncertain. It is estimated that indirect formaldehyde could be responsible for 50 to 90 percent of the total formaldehyde in the atmosphere; hence, the midpoint of 70 percent was used in the attached table. As a result, 30 percent of the total formaldehyde base cancer cases were assigned to direct formaldehyde and 70 percent of the total formaldehyde base cancer cases were assigned to indirect formaldehyde.(3)

Unlike the other pollutants, direct formaldehyde emissions from vehicles fueled with neat methanol may be greater than those from gasoline-fueled vehicles. The 200 percent increase in direct formaldehyde emissions contained in the table was estimated assuming that formaldehyde emissions from future

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(1) "Air Toxic Emissions and Health Risks from Motor Vehicles," Jonathan M. Adler and Penny M. Carey, Air and Waste Management Association Paper 89-34A.6, 1989.
(2) "Emission Standards for Methanol-Fueled Motor Vehicles and Motor Vehicle Engines," EPA Final Rulemaking, Federal Register Part 86, No. 68, 14426-14613, April 11, 1989.
(3) "Source Assessment of Formaldehyde Emissions," Radian Corporation, September 3, 1985.

gasoline-fueled vehicles under the proposed new standards and vehicles optimized for methanol are 5 milligrams per mile and 15 milligrams per mile, respectively. A catalyst is required to control formaldehyde from methanol vehicles. The potential exists to optimize the catalyst to achieve formaldehyde levels similar to gasoline vehicles, if necessary.

In contrast to direct formaldehyde emissions, it is believed that indirect formaldehyde formation with neat methanol vehicles will decrease relative to gasoline-fueled vehicles. This is due to the decrease in reactive hydrocarbons emitted from methanol-fueled vehicles relative to gasoline-fueled vehicles (methanol is not very reactive). A decrease in reactive hydrocarbons emitted is expected to result in less indirect formaldehyde formed.(1) The use of neat methanol is estimated to result in an 80 percent reduction in reactive hydrocarbons and, thus, an 80 percent reduction in indirect formaldehyde.

With the use of neat methanol, the reduction in cancer cases from indirect formaldehyde is projected to roughly offset the increase in cancer cases from direct formaldehyde. As a result, the net impact is projected to be no increase in formaldehyde cancer cases with neat methanol use. However, the exposure and health effects tradeoffs associated with direct formaldehyde emissions and indirect formaldehyde exposure will continue to be studied.

More information on the air toxics implications of the clean, alternative fuels program, is included in the following references:

1. "Emission Standards For Methanol-Fueled Motor Vehicles and Motor Vehicle Engines," EPA Final Rulemaking, Federal Register Part 86, No. 68, 14426-14613, April 11, 1989.

2. Paul A. Machiele, "Flammability and Toxicity Tradeoffs with Methanol Fuels," SAE Paper 872064, November 1987.

3. Richard Snow, Linnie Baker, William Crews, C.O. Davis, John Duncan, Ned Perry, Paula Siudak, Fred Stump, William Ray, James Braddock, "Characterization of Emissions from a Methanol Fueled Motor Vehicle," Journal of the Air Pollution Control Association, 39, No. 1, 4854, January 1989.

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(1) "Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards and Test Procedures for Methanol-Fueled Vehicles and Engines," EPA Office of Mobile Sources, January 1989.

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7. "Summary and Analysis of Comments on the Notice of Proposed Rulemaking for Emission Standards and Test Procedures for Methanol-Fueled Vehicles and Engines," EPA Report, January 1989.

8. Proceedings from 8th International Symposium on Alcohol Fuels, Tokyo, Japan, November 1988.

9. Proceedings of the Methanol Health and Safety Workshop, South Coast Air Quality Management District, November 1988.

10. F. Lipari, R.L. Williams, "Formaldehyde, Methanol, and Hydrocarbon Emissions from Methanol-fueled Cars," Air and Waste Management Association Paper 89-124.3, June 1989.

11. "Request for Applications, Phase Two, Set II, Research Agenda," RFA 85-1, "Health Effects of Aldehydes", Health Effects Institute, July 24, 1985.

12. "Motor Vehicle Toxics: Assessment of Sources, Potential Risks and Control Measures," State of California, Air Resources Board Report, June 1989.

13. Penny M. Carey, "Air Toxics Emissions From Motor Vehicles," EPA Office of Air and Radiation Report, September 1987.

14. Penny M. Carey and Joseph H. Somers, "Air Toxics Emissions From Motor Vehicles," Air Pollution Control Association Paper 88-128.1, June 1988.

15. Jonathan M. Adler and Penny M. Carey, "Air Toxics Emissions and Health Risks from Motor Vehicles," Air and Waste Management Association Paper 89-34A.6, June 1989.

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17. "Formaldehyde Health Effects," Midwest Research Institute Report for EPA Office of Mobile Source Air Pollution Control, December 1981.

18. "Formaldehyde," Documentation of the Threshold Limit Values, AGCIH, 1985.

19. "Report on the Consensus Workshop on Formaldehyde," Environmental Health Perspectives, 58, 323, 1984.

20. "Assessment of Health Risks to Garment Workers and Certain Home Residents from Exposure to Formaldehyde," EPA Office of Pesticides and Toxic Substances Final Draft Report, March 1987.

21. "Formaldehyde and Other Aldehydes", Committee on Aldehydes, National Research Council, National Academy of Sciences, 1981.

22. "Characterization of Exhaust Emissions from Methanol and Gasoline-Fueled Automobiles," Southwest Research Institute Report for EPA Office of Mobile Source Air Pollution Control, Report EPA 460/3-82-004, August 1982.

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25. Kathleen M. Nauss, "An Evaluation of the Human Health Effects of Automotive Methanol Vapors," Health Effects Institute, presented at the South Coast Air Quality Management District Methanol Health and Safety Workshop, November 1, 1988.

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34. "A Review of the Toxicity of Methanol", Dr. John J. Clary, Presented at the First International Conference on Methanol, May, 1983.

35. "Biological Monitoring of Persons Exposed to Methanol Vapors," V. Sedivec, et.al., Int. Arch. Occup. Environ. Health, 48: 257-271, 1981.

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39. "Neonatal Behavioral Toxicity in Rats Following Prenatal Exposure to Methanol," R. Infurna, B. Weiss, Teratology, 33: 259-265, 1986.

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42. Craig A. Harvey, "Determination of a Range of Concern for Mobile Source Emissions of Methanol," EPA Office of Mobile Sources Report TSS 83-6, July 1983.

43. Penny M. Carey, "Determination of a Range of Concern for Mobile Source Emissions of Formaldehyde Based Only on its Toxicological Properties," EPA Office of Mobile Sources Report TSS 83-5, July 1983.

44. "Metabolism, Ocular Toxicity and Possible Chronic Effects of Methanol," Dr. Kenneth McMartin, Presentation at the Methanol Health and Safety Workshop, South Coast Air Quality Management District, November 2, 1988.

Global Warming

Another environmental issue raised is the effect of methanol use on global warming. Much of this effect is dependent on the feedstock used to produce the methanol.

In the near term, the most economically and environmentally attractive fuel methanol feedstock is associated natural gas (gas which is co-produced with petroleum). Presently, a vast quantity of associated gas is either flared or vented, resulting in energy wasted and in emissions of carbon dioxide (CO_2) and methane (CH_4), both highly effective greenhouse gases, to the atmosphere. Clearly, if this wasted energy resource were used to supply a fuel that could power vehicles (that would otherwise have used gasoline produced from crude oil), a significant greenhouse gas emission reduction would result. Greenhouse gases which would have been emitted at flaring or venting sites would instead be emitted by the methanol transportation sector. The aggregate short-term result would be a percentage reduction in greenhouse gas emissions due to the U.S. transportation sector, roughly equivalent to the percent of vehicles operating on methanol fuel.

In the long term, venting and flaring of natural gas are expected to decrease as new markets are found for co-produced natural gas. Under such conditions remote natural gas would likely be used as a methanol feedstock. The greenhouse gas contribution of improved efficiency methanol vehicles operating on methanol made from remote natural gas would be roughly equivalent or slightly lower than that of their gasoline counterparts.

Coal, on the other hand, produces a greater amount of CO_2 per unit energy delivered than any other conventional fossil fuel (because of its higher carbon-to-hydrogen ratio). In addition, large quantities of methane are released from coal formations during mining, also contributing to the global warming problem.

Based on EPA analysis, if no measures are taken to prevent the release of CO_2 from coal-to-methanol plants, the greenhouse gas emissions of coal-based, present technology, methanol vehicles would be roughly twice those of gasoline vehicles. Improved efficiency methanol vehicles would contribute 70 to 80 percent more greenhouse gas emissions than their gasoline counterparts. However, if CO_2 recovery and disposal technology is developed and employed, advanced technology methanol vehicles would have roughly the same and potentially even less impact on long-term global warming than crude-oil-based gasoline vehicles. Clearly, more research is needed to identify the feasibility and cost of minemouth methane recovery and disposal as well as production plant CO_2 recovery and disposal technologies.

The sale of alternative-fueled vehicles will generate CAFE credits under the Alternative Motor Fuels Act of 1988. To the extent that automobile manufacturers and purchasers accept lower fuel economy of the gasoline-powered portion of the fleet, CAFE could no longer be a binding constraint and an increase in gasoline consumption and global warming could result. This effect would be reduced to the extent that consumers demand good fuel economy and that methanol is produced from currently vented and flared natural gas.

More thorough discussion on the effects of alternative fuels on global warming is covered in the following references:

1. "Global Warming as Affected by Fuels Choices," Acurex Corporation, prepared for the 1989 SAE Government/Industry Meeting, May 2-4, 1989.

2. Timothy L. Sprik, "Alternative Transportation Fuels and the Greenhouse Effect," U.S. EPA, [Draft Report].

3. "Coal-to-Methanol: An Engineering Evaluation of Texaco Gasification and ICI Methanol-Synthesis Route," prepared by Fluor Engineers and Constructors, Inc. for Electric Power Research Institute, EPRI AP-1962, Project 832-4, August 1981.

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6. "A Carbon Dioxide Power Plant for Total Emission Control and Enhanced Oil Recovery," Frederick L. Horn and Meyer Steinberg, Brookhaven National Laboratory, BNL-30046, August 1981.

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8. "Comparing the Impact of Different Transportation Fuels on the Greenhouse Effect," Stefan Unnasch, Carl B. Moyer, Douglas D. Lowell, Michael D. Jackson, Acurex Corporation, December, 1988.

9. "Coalbed Methane in the Black Warrior Basin," Thompson, Dan A., Telle, Whitney R., Alabama Geology, Resources, and Development, GRI Quarterly Review of Methane from Coal Seams Technology, Volume 4, Number 3, February 1987.

Spill Issues

If methanol were involved in a spill or leak into the ocean, into rivers, onto land, or into drinking water supplies, the question arises as to whether a greater environmental and public health hazard would be posed relative to a petroleum fuel spill or leak. A methanol fuel leak or spill into aquatic systems or on land indeed poses environmental and health concerns because of the fuel's toxic effects, and it would be expected that there would be a larger number of spills because of the larger quantities of methanol fuel that would have to be transported. However, as a result of methanol's inherent properties of water solubility, biodegradability, and relative ease of complete evaporation, it could quickly dilute to non-toxic concentrations, disperse downstream, and decompose if spilled into large bodies of water, and evaporate or decompose if spilled on land areas. Thus, in many scenarios, a methanol spill should not be as hazardous as a petroleum spill. One scenario which must be analyzed in much greater detail, however, is groundwater contamination, given methanol's solubility in water.

In comparison to petroleum fuels, a tanker spill of methanol into the ocean should pose less risk to aquatic life. Methanol's water solubility allows for rapid dispersion and dilution and, therefore, short exposure durations. Also, methanol's quicker biodegradation than that of crude oil, diesel fuel, or gasoline results in shorter residence times of the fuel and faster recolonization of life at spill sites, with less severe long-term effects of spills on animal life and on the environment. In general, cleanup of methanol spills requires less extensive efforts and costs than cleanups associated with spills of water-insoluble petroleum fuels. Small methanol spills usually do not require any cleanup efforts because of the effectiveness of natural biodegradation, while large methanol spills may require aeration of the water (to supply depleted oxygen to marine life and speed biodegradation) and/or use of methanol-destroying bacteria.

Methanol spills into rivers and other moving bodies of water also benefit from the fuel's water solubility and biodegradation. Again, in contrast to petroleum fuels, methanol spilled into a river from, for example, a barge, is quickly diluted and carried downstream. Cleanup of a methanol fuel spill into a moving body of water would be handled similarly to that of a spill into the ocean.

Although, like petroleum fuels, methanol is toxic to plant and animal life, its toxic effects after a spill onto land are of shorter duration than those exhibited by a petroleum fuel spill. Again, methanol's inherent properties of relative ease of complete evaporation and biodegradability play a positive role. Its more rapid evaporation from the earth allows for less to be absorbed. (It is important to note that while some of the lighter ends of gasoline evaporate very quickly, its heavy components require long periods of time before evaporation occurs.) However, if absorbed, methanol's larger degree of biodegradability facilitates decomposition by micro-organisms present in the soil. Because of its shorter retention periods near a spill site, cleanup of a methanol spill on the earth requires less effort than that of a petroleum fuel spill. In the event of a massive spill, however, enhancement of the natural biodegradation process of methanol may be beneficial.

Since methanol's solubility in water and, hence, rapid dilution and dispersion are considered advantages in spills into large and/or quickly moving water masses, most scenarios where groundwater contamination is at risk would be less severe with methanol than with petroleum. In some situations, however, such as a river spill located very near a drinking water supply or leakage from an underground storage tank located very close to a well, methanol may indeed be dispersed more quickly into drinking water supplies contained in aquifers or wells. Coupling its ready dilution in water with the fact that methanol contains no "built-in" detection mechanism of odor, color, or taste, toxic concentrations may form before its presence is recognized. Studies on the disposition of methanol spills very near drinking water supplies are not readily available, and further study by EPA and other organizations is warranted. In any event, the use of additives in methanol to impart a color, odor, and/or taste to the fuel are essential to permit methanol to be detected in groundwater supplies to facilitate its cleanup before harmful quantities were ingested.

For more detailed information on the topic of methanol spills into the various water and land media as well as on the comparison of methanol and petroleum spills, the following references may be consulted:

1. "Assessment of Methane-Related Fuels for Automotive Fleet Vehicles: Technical, Supply, and Economic Assessments," Report No. DOE/CE/50179-1, Energy Conservation Directorate for U.S. Department of Energy, February 1982.

2. Peter N. D'Eliscu, A Compilation of Work on the Topic of the Environmental Consequences of Methanol Spills, Acurex Corporation, 1987.

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Safety Issues

Methanol, like all combustible fuels such as gasoline, poses a potential human safety risk. Because of the differences in the physical and chemical properties of methanol and gasoline, the human safety risks of neat methanol are dramatically different than those of gasoline. Based on what is currently known, methanol would appear to offer fire safety benefits compared to gasoline. Further research is necessary to identify those areas where precautions are needed. The two key areas for comparison are fire safety and human toxicity.

With regard to fire safety of methanol, there are two main advantages and two main disadvantages. The advantages, along with the possibility for mitigating the disadvantages, cause the fire safety risks of methanol to be lower than for gasoline. Methanol's low volatility, relatively high lower flammability limit*, and low vapor density cause it to be much less likely to ignite in an open area resulting from a spill of fuel or release of vapor. In addition, once it does ignite, methanol's low heat of combustion and high heat of vaporization cause it to burn much slower and less violently, releasing heat at roughly one-fifth the rate of gasoline. However, these same combustion properties cause methanol to be in the flammable range inside fuel storage tanks under normal ambient temperatures (45-108°F), while gasoline is virtually always too rich to ignite. Fortunately, precautions can be taken to prevent either flammable vapor/air mixtures from forming in storage tanks (e.g., nitrogen blanketing, bladder tanks, floating roof tanks) or to prevent ignition sources from entering the tanks (e.g., flame arresters, removing or modifying in-tank electrical devices) thereby mitigating any additional risk. The other disadvantage of methanol is that due to the lack of any large carbonaceous particles in its products of combustion, pure methanol burns with a light blue flame which is essentially invisible to the human eye in bright daylight. This can represent a serious safety concern for fire identification and its accompanying warnings. The only means of detecting the burning methanol in such situations is by feeling the heat being generated or seeing the "heat waves." Fortunately, the fraction of fires which occur in broad daylight, where no other substances are present to provide a

* Methanol will not ignite in air at concentrations below about 6 percent while gasoline will ignite at concentrations as low as 1.4 percent.

visible flame, is estimated to be very low (nearby substances such as roadside grasses, vehicle plastic and rubber components, engine oils, building structures, etc. also become involved). As a result, in many cases the lack of flame luminosity is not a serious concern. Work is continuing toward finding an appropriate luminosity additive to allay all concerns.

With regard to human toxicity, the Health Effects Institute, an independent non-profit research organization funded jointly by EPA and the automobile industry, concluded in a May 1987 report that "the weight of available scientific evidence indicates that exposure to methanol vapors is not likely to cause adverse health effects. Health concerns regarding methanol vapor should not prevent government and industry from encouraging the development and use of methanol fuels, assuming that such development and use are otherwise in the public interest." Nevertheless, EPA supports further research in this area, especially with respect to chronic exposure to low levels of methanol. Such research will help to determine the type of emission control equipment required.

One advantage of methanol is that there are no known long-term carcinogenic effects resulting from exposure to methanol. On the other hand, benzene in gasoline is a proven carcinogen, and the gasoline vapor itself is a possible carcinogen.

Methanol, however, is more of a hazard in terms of ingestion. Neat methanol has no taste, color, or detectable odor, and, as a result, may be more likely to be ingested than gasoline. In addition, as little as 2 teaspoons of methanol have resulted in death, while 5 to 30 times this level is a normal lethal range if treatment is not given. Small amounts of gasoline aspirated into the lungs can also result in death, but this occurrence is statistically rare. The main causes of motor fuel ingestion are siphoning by adults and ingestion by children of fuels stored in containers around the home. The vast majority of these occurrences can be avoided by preventing siphoning from vehicles through the use of flame arresters. In addition, as was discussed above, additives to neat methanol can be used to give it an identifiable odor, taste, and/or color in order to reduce the chance of accidental ingestion.

Safety issues of methanol fuel use, in particular fire safety and human toxicity, are discussed in more detail in the following references:

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