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THE ENVIRONMENTAL PROTECTION AGENCY VIEW OF METHANOL AS A TRANSIT BUS FUEL

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Jeff Alson
Assistant to the Director
Emission Control Technology Division
Office of Mobile Sources
Environmental Protection Agency

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Environmental Protection Agency (EPA) interest in transit buses has increased significantly in the last few years. Concerns over existing diesel bus pollution and enthusiasm over the potential of methanol to alleviate these concerns have both contributed to this increased interest. This paper will give an overview of the transit bus issue from an EPA perspective, summarizing our current outlook on diesel buses, discussing methanol as a general motor vehicle fuel, and focusing on the benefits of methanol as a future transit bus fuel.

A Reassessment of Diesel Bus Pollution

Historically, transit buses have not been considered to be a significant environmental problem. In any urban area, the number of transit buses is only a minute fraction of the total number of motor vehicles. Powered by diesel engines, which inherently produce low levels of hydrocarbon (HC) and carbon monoxide (CO) emissions, total mass emissions of most pollutants from transit buses are dwarfed by aggregate emissions from passenger vehicles, large trucks, and stationary sources such as power plants and factories. In addition, from a technical perspective, there has not been a promising bus or truck alternative to the diesel cycle engine operated on diesel fuel. Accordingly, EPA regulation of heavy-duty trucks and buses has lagged behind that of passenger cars and light trucks, and current EPA standards require only token control measures on new heavy-duty diesel engines.

A number of developments have forced EPA to reexamine the diesel bus issue. As EPA has reduced emissions from other sources (for example, new passenger car HC and CO emissions have been reduced by over 90 percent in the last fifteen years), bus emissions have become proportionally more important. Public health concerns with diesel particulate matter (PM) and oxides of nitrogen (NOx) emissions have increased, the former because of evidence that it contains carcinogenic compounds and the latter because air quality projections show that certain areas of the country will exceed EPA's ambient standard during the 1990s, and both of these pollutants are emitted in relatively large amounts by diesel engines. As our ability to analyze motor vehicle emission impacts has become more sophisticated, we have determined that public exposure to transit bus pollution is much higher than to many other pollution sources, on a per unit mass basis: buses are operated exclusively in urban areas, typically over the busiest roadway corridors with maximum population exposure, the pollution is emitted at ground level directly into the human breathing zone, and EPA and local environmental officials

receive a high frequency of complaints about bus pollution and odor. Finally, recent EPA testing has indicated that actual diesel bus emissions of certain pollutants, such as CO and PM, are much higher than previously thought.

Table 1 lists the current and future emission standards which have been established for new engines to be utilized in transit buses, as well as ranges for the emissions of current technology engines. It can be seen that current diesel bus engines are comfortably below the current HC and CO standards of 1.3 and 15.5 grams per brake horsepower-hour (g/bhp-hr), respectively, and that these standards are not expected to change in the future. The situation with NOx and PM standards is in a state of flux, however. We currently have a NOx standard of 10.7 g/bhp-hr, which represents very little control, if any, and no PM standard (there is a smoke standard which constrains PM emissions somewhat). On March 15, 1985, EPA promulgated new rules which will, for the first time, require meaningful NOx and PM reductions from heavy-duty diesel truck and bus engines. Interim standards beginning in 1988 will require minor improvements on some engine models. By 1991, new diesel bus engines will be subject to a NOx standard of 5 g/bhp-hr, similar to a standard already in effect in California. This will require some type of engine modification on most new bus engines. Also beginning in 1991, new bus engines will have to meet a 0.1 g/bhp-hr PM standard. This is a very significant reduction in allowable PM emissions, and will likely require the application of trap oxidizers, exhaust aftertreatment devices which continuously filter and periodically oxidize PM.

The lower diesel bus emission standards in 1991 have certainly contributed to the interest of diesel engine manufacturers in alternative fuels. The application of trap oxidizers and NOx controls will undoubtedly raise the initial purchase price, and probably the fuel consumption as well, of transit bus engines. A second motivation is simply the realization that we will not have abundant supplies of cheap diesel fuel forever, and that an alternative fuel will ultimately be necessary.

Methanol: The Transportation Fuel of the Future

Whether examined from an energy, environmental, or economic standpoint, methanol is a very promising alternative motor vehicle fuel. Of course, the historical context for interest in methanol, and all alternative liquid fuels, involves the oil price shocks of the 1970s. American society had prospered on cheap and plentiful oil, and it was only after

the OPEC oil embargo of 1973-74 that we realized that petroleum was a finite and valuable resource. Our vulnerability with respect to energy security was reinforced in 1979-80 when a relatively minor cutoff of crude oil from Iran caused major havoc with world oil prices. Prices rose from $3 per barrel in the early 1970s to nearly $40 per barrel in 1981. Oil import payments, which peaked at $80 billion in 1980, became a major drain on American capital, and contributed to a decline in our international trade balance.

Although the present world oil price and supply situation is much improved, with plentiful supplies and falling prices, we cannot afford to become overconfident. Domestic oil production, which has been constant for several years, is projected to decline in the late 1980s, as shown in Figure 1. The combination of lower domestic oil production and increased economic growth is expected to significantly increase our appetite for imported oil. In addition, world economic recovery and growth and falling crude production in other non-OPEC areas are expected to significantly increase world oil prices in the 1990s. It is expected that our oil import bill will exceed $100 billion per year by the early 1990s if a satisfactory liquid fuel substitute is not found. Figure 2 indicates that our cumulative international trade deficits are increasing at a high rate, due to record merchandise trade and current account deficits in 1984. Higher oil import bills in the 1990s can only worsen our trade difficulties. Since, as shown in Figure 3, approximately 60 percent of U.S. petroleum consumption is in the transportation sector, it is clear that the U.S. will ultimately require a liquid fuel alternative to petroleum which can be produced from domestic energy resources.

From an energy perspective methanol is an attractive alternative. It can be produced in very large volumes from a variety of domestic feedstocks such as natural gas, biomass, and, most importantly, all types of coal. Our huge domestic reserves of coal, evidenced in Table 2, will undoubtedly be a feedstock for alternative liquid fuels in the future. The production technology for coal-to-methanol plants is technologically proven as both the coal gasification and methanol synthesis processes are in use today. The fact that coal would go through a gasification step would permit any sulfur in the coal to be easily removed allowing the use of high-sulfur coal. As a liquid fuel, methanol would generally be compatible with existing vehicle and distribution systems. Finally, it has been known for decades that methanol is a very efficient, high-octane motor vehicle fuel. From an overall energy efficiency perspective, methanol would likely provide the maximum number of vehicle miles per ton of coal feedstock.

Methanol has always been considered to be a very clean-burning fuel; in fact, its low emissions, especially of nitrogen oxides, was a primary impetus for many of the initial methanol research projects of the early 1970s. Of course, we now have much more stringent passenger car emission standards, and sophisticated emission control technologies have been developed to control emissions from gasoline-fueled cars. Compared to gasoline-fueled vehicles, methanol vehicles would likely emit lower levels of reactive hydrocarbons, leading to a projected decrease in photochemical oxidant levels. Engine-out nitrogen oxide levels would also be lower, though whether vehicle emission levels would be lower would depend on the emission control system used (i.e., manufacturers might choose to use a lower cost catalyst).

The environmental benefits of methanol are most evident when considered as a substitute for diesel fuel. Diesel engines inherently emit high levels of particulate and nitrogen oxide emissions, and trucks and buses are major sources of these pollutants in many urban areas. Methanol engines tend to emit very low levels of both of these pollutants. Methanol substitution for diesel fuel would also reduce reactive hydrocarbon and sulfur dioxide emissions as well. From an environmental perspective, the use of methanol provides the opportunity for vehicle manufacturers and consumers to achieve the energy efficiency of a diesel engine but with exhaust emissions comparable to or better than the cleanest gasoline engine. Bus emissions will be discussed in more detail later in this paper.

Of course, fuel economics will be vital to the viability of any alternative liquid fuel. EPA has studied this issue extensively and concluded that methanol would be the most cost-effective liquid fuel, on a dollar per mile basis, of any of the candidate fuels which can be produced from coal. When methanol would be competitive with petroleum fuels is very dependent on world oil prices. Our studies indicate that methanol would be competitive with gasoline from $35 per barrel oil and competitive with diesel fuel when crude oil prices reach $45 per barrel. Even assuming that there will be no world oil supply disruptions, most forecasts are that world oil prices will rise above these levels in the 1990s.

There is a growing consensus that methanol is our most promising alternative transportation fuel. Both Ford and General Motors have active methanol vehicle development programs and various foreign manufacturers are also involved in the area. Many energy and chemical industry firms have studied the economic feasibility of coal-to-methanol production plants,

though plans are presently on hold due to the large methanol surplus and falling world oil prices. Methanol vehicles are currently being evaluated by private and public sector fleet operators throughout the U.S., such as the Bank of America and the California Energy Commission.

Interest in methanol development has reached the highest levels of our federal government and both major political parties. The Administration has formed a Methanol Working Group composed of representatives of 15 different executive agencies and White House staffs. The primary purpose of the working group is to review regulatory requirements which might inhibit consumer use of methanol. Various pieces of proposed legislation have attracted bipartisan support in Congress including federal fleet demonstrations, explicit appropriations for methanol bus purchases, the establishment of a formal interagency commission on methanol, and changes in methanol fuel taxation. Given the interest by high-ranking members of both parties, it is expected that such proposals will continue to be considered.

Thus, with respect to environmental, energy, and economic considerations, we believe methanol is the most promising alternative transportation fuel. The conversion of our national vehicle fleet to pure methanol could eliminate our need for oil imports with concomitant benefits such as an improved balance of trade, insurance against the economic dislocations caused by another oil price shock, and increased national security. The redirection of the U.S. wealth now going for oil imports into domestic coal-to-methanol production could increase domestic economic growth and employment and would provide a needed market for high-sulfur coal. And, at the same time, the use of methanol in motor vehicles would improve urban air quality.

The Potential for Methanol as a Transit Bus Fuel

While we believe methanol has the potential to ultimately displace petroleum fuels in all motor vehicle applications, it is particularly attractive at the present time for use in transit buses. There are several reasons why methanol transit buses could be implemented much more easily than could a general fleet transition to methanol. First, because most transit authorities are public agencies, they should be sensitive to public complaints about the environmental problems of diesel buses and the benefits to be gained from operating methanol buses. Transit agencies typically receive operating subsidies from local units of government, and this provides a leverage point for citizens interested in reducing air

pollution. Even more directly, since the federal government provides up to 80 percent of the funds used to purchase new urban buses, it could directly promote interest in methanol buses by providing financial inducements for technology transfer or by simply requiring that all federal monies be used for methanol bus purchases. Second, transit authorities have centralized fueling sites which could be modified to store and dispense methanol fairly easily. This means that a methanol bus implementation program would be largely immune from the distribution problems which would be associated with the widespread transition to a fuel like methanol, with its different chemical properties, requiring that scores of thousands of private service stations be capable of storing and dispensing it. Finally, because transit systems also have centralized maintenance facilities, there would be far fewer concerns over the proper maintenance and repair of a "new" or at least different engine technology. Thus, urban buses are probably the most appropriate vehicles to be initially fueled with methanol.

Several heavy-duty engine manufacturers are now involved in methanol research programs. Despite the fact that research into the use of methanol in diesel engines is a fairly recent phenomenon, manufacturers have already achieved considerable progress. Three manufacturers have developed methanol-fueled diesel-cycle bus engines: M.A.N., Mercedes-Benz, and General Motors. M.A.N.'s involvement in the German Alcohol Fuels Project led them to modify an existing 11.4-liter, six-cylinder, direct-injected, naturally-aspirated, four-stroke diesel engine for pure methanol combustion. The two key aspects of the modification were the addition of spark ignition and the functional separation of fuel injection and mixture formation through wall deposition of the methanol. M.A.N. is now developing a turbocharged version of this same methanol bus engine.

Mercedes-Benz has designed a 11.4-liter, six-cylinder, spark-ignited engine to operate on gaseous methanol, in order to take advantage of methanol's relatively low boiling point (permitting vaporization) and high heat of vaporization (increasing usable energy). The engine, adapted from a design originally intended for operation on natural gas and propane, features a fuel vaporizer which utilizes heat energy from engine cooling water.

General Motors has only recently become involved in methanol bus engine research. GM selected its 9.0-liter, six-cylinder, direct-injected, turbocharged, two-stroke diesel engine, used in most new U.S. transit buses, as its baseline engine. It was found to be surprisingly easy to autoignite

pure methanol in the two-stroke engine at normal engine operating temperatures by controlling the exhaust gas scavenging process to produce the requisite in-cylinder conditions at the time of fuel injection. In effect, much of the exhaust gas is maintained in the cylinder thus providing sufficient temperatures for methanol ignition. Glow plugs were added to the engine for use in cold starting and light-load operation.

Each of these three manufacturers now has methanol buses in various demonstration programs throughout the world. Prototype methanol buses are now operating in revenue service in San Francisco (GM and M.A.N.), Berlin (M.A.N. and Mercedes), Auckland, New Zealand (M.A.N. and Mercedes), and Pretoria, South Africa (Mercedes). Each bus has had some problems, but none appear to be insurmountable. Both the engine manufacturers and the demonstration sponsors have been pleased with each of the programs.

The most critical ongoing demonstration program for U.S. policymakers, both because of the manufacturers involved and its accessibility, is the one in San Francisco sponsored by the California Energy Commission. Two GM and M.A.N. methanol buses, which went into service for the Golden Gate Bridge, Highway, and Transportation District in January and July of 1984, respectively, will be operated in normal revenue service until the end of 1985, at which time it is likely that additional funding will be sought to continue the demonstration. The program has been designed to provide important information with respect to operating cost, fuel and oil consumption, emissions, maintenance, driveability, durability, and consumer and driver reaction. Experience gained from this program will be very helpful in planning for more comprehensive demonstrations in the future. In general, the San Francisco demonstration has been very successful in proving the feasibility of methanol transit buses. The M.A.N. bus has been particularly impressive with very few maintenance problems and an energy efficiency equivalent to its diesel counterpart both in service and on track fuel economy tests. As of October 1985, the M.A.N. bus had accumulated 37,000 miles. The GM bus was beset with some problems early in the program, but is now running well and has accumulated 27,000 miles. The GM bus has not yet reached an energy efficiency equivalent to the diesel. Both of the buses have exhibited performance equivalent to diesel buses. For more detailed information on this program, the reader should consult Society of Automotive Engineers paper number 850216.

A second U.S. demonstration, sponsored by the Florida Department of Transportation and UMTA, is also ongoing. Its purpose is to determine the costs and benefits of retrofitting in-use GM 71-series diesel bus engines to methanol. Three engines have been converted in 1985 and will be put into service in Jacksonville, Florida for six months in early 1986. This program is more fully described in Society of Automotive Engineers paper number 841687.

Based on the promising results to date, additional demonstrations, involving larger numbers of buses and the active interest and participation of individual transit authorities, are being planned. Seattle Metro Transit has signed a contract to purchase 10 M.A.N. methanol buses,with delivery expected in late 1986. The Southern California Rapid Transit District is expected to solicit bids for 30 methanol buses in the near future. Officials in several other cities, such as New York and Denver, have also expressed interest.

It is becoming increasingly clear that environmental considerations comprise the primary driving force toward the use of methanol in transit buses. While interest in alternative fuels is generally a function of oil prices and availability, the enthusiasm for methanol buses has grown significantly in the last two years despite a world oil glut and falling oil prices. Our discussions with local environmental officials and individual transit authorities have indicated that there would be a high value associated with a transit bus fuel which was cleaner than diesel fuel. What would be the environmental implications of substituting methanol buses for diesel buses?

EPA has tested many diesel bus engines down through the years. Until very recently EPA has relied exclusively on engine dynamometer testing which simplifies the laboratory expense of characterizing an engine which may be used in a number of truck and bus chassis applications. In addition, an engine dynamometer can be smaller and cheaper than a chassis dynamometer. Data collected prior to the late 1970s was generated over steady-state engine testing which is not considered to be very representative of in-use transit bus operation. Much of the more recent data was generated over the EPA heavy-duty transient engine test procedure, which is used for official EPA certification purposes. This involves operating an engine over a test cycle that consists of engine speed and load transients which were designed to simulate intercity truck usage (truck operation was selected for the cycle design because trucks outnumber buses). The first column in Table 3 gives the average engine emissions data for three new diesel bus engines which EPA has tested over our certification transient engine test cycle.

Of course, the relevant information for air quality models is the grams per mile (g/mi) that a vehicle is emitting. Historically, EPA has typically used a "conversion factor" of between 3 and 4 to convert engine emissions in g/bhp-hr to vehicle or chassis emissions in g/mi. Recently, EPA has tested 7 diesel buses pulled directly from operating service and operated on a chassis dynamometer over emission test cycles designed to simulate transit bus operation. Three of these buses were GMC RTS II buses from the Houston bus fleet which were equipped with DDAD 6V-92TA diesel engines. Four GMC RTS II buses with DDAD 6V-71 diesel engines from the San Antonio transit authority were also tested. These buses had accumulated between 55,000 and 247,000 miles prior to testing. Two chassis test cycles were used, an EPA bus driving cycle and the central business district phase of the SAE Type II Fuel Consumption Test Procedure for buses. Both of these chassis cycles involve transient operation with low average speeds and high acceleration rates, and both cycles have yielded fuel economy values which correlate well with field data. The second column in Table 3 gives the average emission data for these 7 buses. It can be seen that multiplying the engine data by a conversion factor of 3 or 4 is pretty reliable for HC and NOx emissions, but that this methodology does not hold for CO and PM emissions. The CO and PM emissions for in-use diesel buses were much higher than predicted by the engine data. The discrepancies reflect some combination of engine aging and wear, maladjustment, or more realistic test cycles. In any case, EPA has concluded that previous projections of diesel bus emissions have been underestimates, and that chassis testing is necessary for accurate quantification of bus emissions.

Nevertheless, until recently there was no methanol bus chassis data, only methanol engine data. Table 4 compares the diesel bus engine emissions data from Table 3 with engine emissions data for the M.A.N. and GM methanol engines. All of these engines were new or nearly new. The M.A.N. methanol engine was tested by the Southwest Research Institute under contract to EPA. The engine was equipped with an oxidation catalytic converter and tested over the EPA transient engine test cycle. The GM methanol engine was tested by GM over the older EPA 13-mode steady-state engine cycle. It did not utilize a catalytic converter. As can be seen, CO and HC emissions were not reported by GM.

The engine data in Table 4 show clearly that methanol, because of the absence of carbon-carbon bonds and fuel impurities such as lead and sulfur, produces very low levels of PM. Besides being a critical environmental benefit in and of itself, the low particulate levels also permit the utilization

of catalytic converters which, as shown by the M.A.N. data, reduce total organics and CO levels as well. The NOx data is mixed. While methanol is considered a low-NOx fuel because of its low flame temperature, the M.A.N. methanol engine actually emitted slightly more NOx than the diesel engines. On the other hand, the NOx emission level from the GM methanol engine is the lowest ever reported to EPA for a heavy-duty engine.

One of the most interesting issues with respect to methanol fuel is organic (or fuel-related) emissions. Organic emissions from diesel (and gasoline) vehicles are comprised almost exclusively of HC compounds (with small amounts of other compounds such as formaldehyde), and EPA regulates these with a single HC standard. Organic emissions from methanol combustion are typically 90 percent (or more) unburned methanol with the remaining fraction being primarily formaldehyde with low levels of HC. As the data in Table 4 show, methanol engines emit considerably lower HC emissions, much greater methanol emissions, and similar levels of formaldehyde compared to diesel engines. Even if overall mass organic emissions were similar, methanol is considered to be less photochemically reactive than most HC compounds. Thus, methanol substitution could reduce the photochemical reactivities of urban atmospheres, resulting in lower ozone levels. Preliminary computer modeling simulations have projected reduced reactivities, and EPA is now in the process of validating these results with smog chamber research.

Just this last summer EPA completed a comprehensive methanol chassis emission test program at Southwest Research Institute with the M.A.N. and GM methanol buses from the San Francisco demonstration program. This is the first such testing of methanol buses anywhere in the world and permits us to directly compare diesel and methanol bus emissions. This comparison is given in Table 5. The diesel bus data, involving 7 in-use GM buses with both 71-series and 92-series engines, are repeated from Table 3. All of these buses were operated over the EPA bus and SAE central business district test cycles. The M.A.N. methanol bus utilized a catalytic converter, while the GM methanol bus (and, of course, the diesel buses) did not. The chassis data in Table 5 generally confirm the engine data in Table 4. The methanol chassis emissions data are particularly impressive for PM and NOx, the two primary pollutants of concern from diesel buses. Both methanol buses yielded PM and NOx reductions compared to the diesel baseline, with the M.A.N. bus especially low on particulate and the GM methanol bus very low on NOx. The M.A.N. bus also emitted low levels of CO and organics as well, due to both an efficient combustion process and the presence of

a catalytic converter. Of particular significance is that aldehyde emissions from the M.A.N. bus were lower than from the diesel buses. The GM methanol bus produced extremely high CO and organics emissions,with the very high methanol (i.e., unburned fuel) emissions an indication that there is still the need for considerable fundamental engine design work to be done with this engine. This should not be surprising since this is the very first methanol bus built by GM. The application of a catalyst would also lower CO and organics emissions (and likely PM as well, since most of the particulate is organic, formed by the combustion of small amounts of lubricating oil).

In summary, initial tests of methanol-fueled diesel engines and buses confirm theoretical expectations that the substitution of methanol for diesel fuel could provide significant emission benefits. PM emissions would be greatly reduced, and would likely be near zero for some engine designs. NOx emissions would be reduced by at least 50 percent. Methanol engines would likely be able to meet any future, more stringent, PM and NOx standards without requiring additional emission controls. Assuming the use of an exhaust catalyst, which EPA believes should be mandatory, methanol engines would also provide reactive HC reductions, with concomitant improvements in atmospheric ozone levels, and CO reductions as well. Present data indicate that catalysts would reduce aldehyde emissions to levels equivalent to or below those of current diesel engines. The only pollutant which would be increased would be unburned methanol although catalysts would reduce it to acceptable levels.

Of course, whether methanol buses become a realistic alternative is in large part dependent upon fuel costs. It is very difficult to project the future operating costs for methanol and diesel buses with a high degree of confidence. Prices for both fuels are currently depressed because of excess capacities, though it is unclear how long these surpluses will continue. Diesel fuel prices are particularly difficult to project given their dependence on world oil prices. Nevertheless, given the vital importance of fuel costs in the operation of a transit authority, it is important to have some idea of the relative operating economics of methanol and diesel fuels.

EPA has performed an analysis to determine when methanol fuel might become competitive with diesel fuel for use in transit buses. Our analysis utilized the following assumptions: 1) Methanol buses will need only the addition of a catalytic converter to meet the 1991 emission standards, 2) The addition of a converter and a larger fuel tank will raise

the cost of a methanol bus by approximately $1000, 3) Methanol buses would achieve energy efficiencies equal to today's uncontrolled diesel buses, 4) Delivered methanol fuel cost to transit authorities in the 1990s would be $0.60 per gallon, based on the large surpluses projected to exist, and 5) Diesel buses would require particulate traps and NOx emission controls to meet the 1991 standards, which will raise the cost of diesel bus engines by $1000 to $3000 and will decrease fuel economy by from 3 to 9 percent.

Based on these assumptions, the "break-even" diesel fuel price would be in the range of $1.23 to $1.33 per gallon. In other words, if diesel fuel cost more than $1.33 per gallon, then methanol fueling would be cheaper. If diesel fuel cost less than $1.23 per gallon, then diesel would continue to be cheaper. Average diesel fuel prices between $1.23 and $1.33 per gallon could result in either methanol or diesel fueling being more efficient depending upon various factors. Energy experts still expect world oil prices to climb in the early 1990s, and diesel fuel prices could certainly exceed $1.33 per gallon by the mid 1990s.

Conclusion

Evidence is mounting that diesel transit bus emissions are of much greater public health concern that previously believed. In view of the relatively high public exposure of urban residents to diesel bus emissions, as well as Congressional directives to control such emissions, EPA has promulgated much more stringent emission standards to take effect in 1991. For the first time, there is a real alternative to the diesel bus which offers several environmental advantages. It appears that methanol buses would provide significant reductions of particulate, smoke, and NOx emissions, and would likely reduce the ozone-formation potential of urban atmospheres. Methanol bus engine efficiencies are expected to equal, and possibly exceed, those of diesel bus engines, and based on current energy price projections methanol buses could be cheaper to operate by the mid 1990s. EPA supports methanol bus research by the automotive industry and strongly urges that transit authorities consider methanol as one alternative for the 1990s.

FIGURE 1

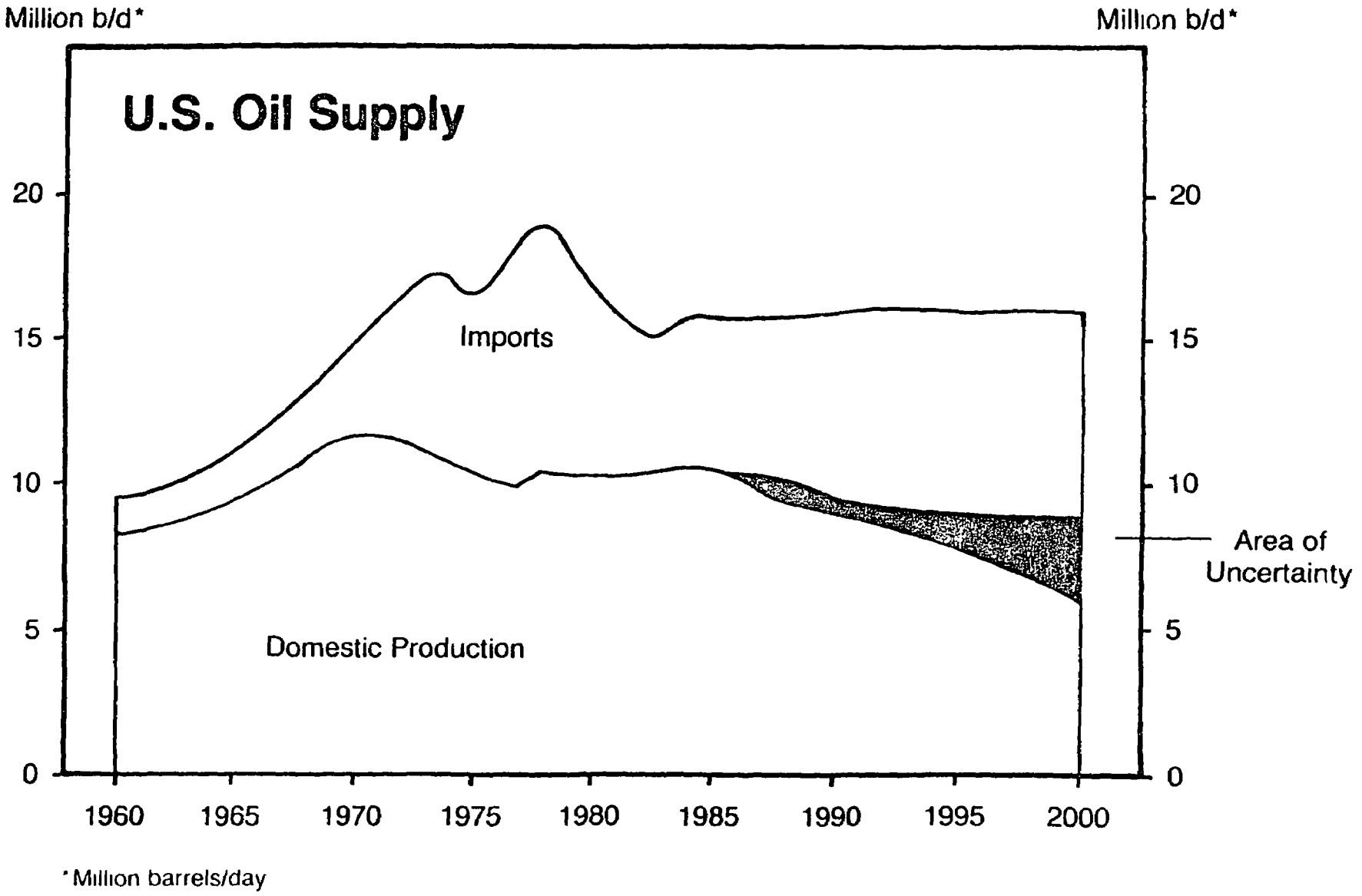

Million b/d*
Million b/d*
U.S. Oil Supply
20
15
10
5
0
Imports
Domestic Production
Area of Uncertainty
1960
1965
1970
1975
1980
1985
1990
1995
2000
*Million barrels/day

FIGURE 2

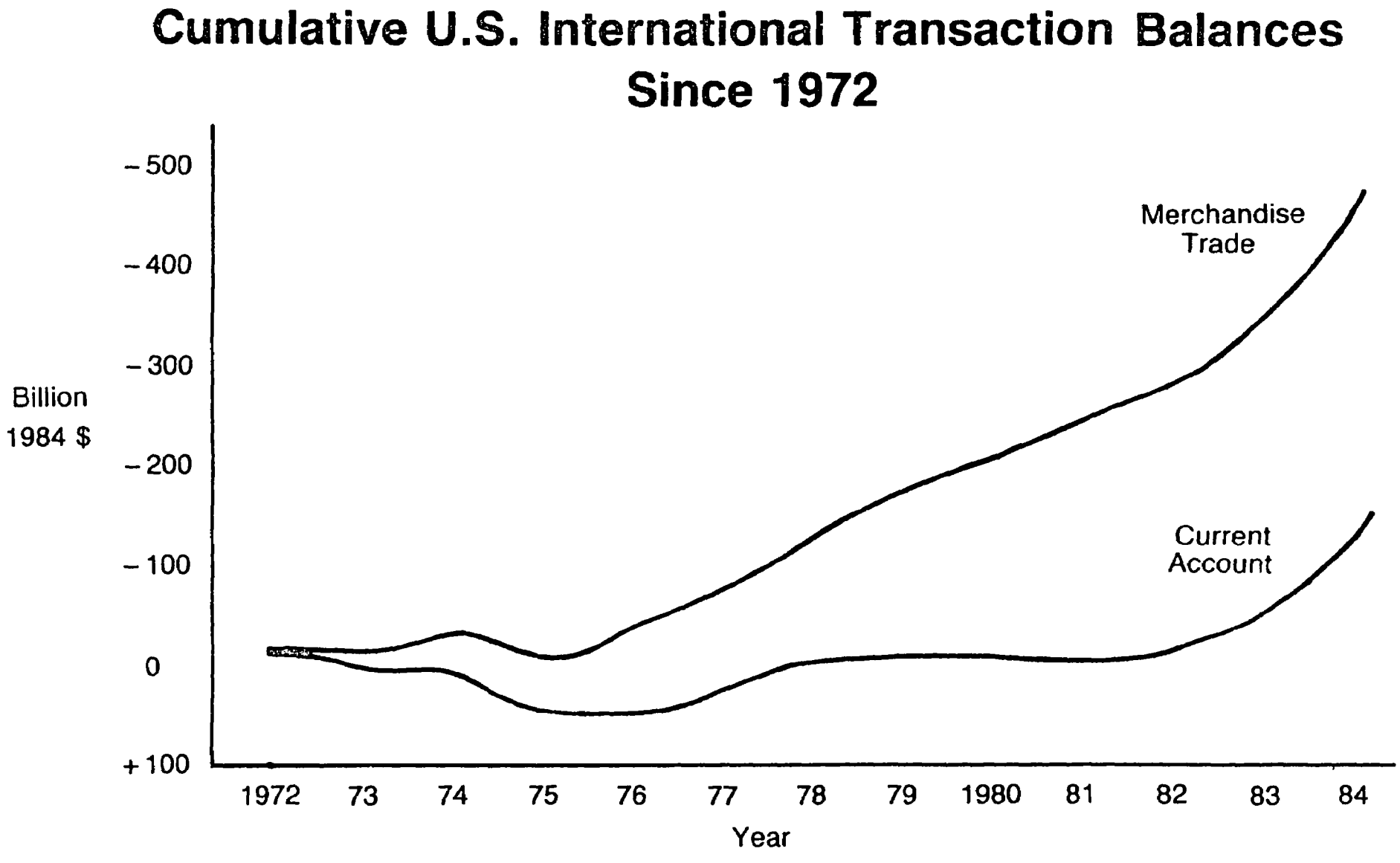

Cumulative U.S. International Transaction Balances
Since 1972
Billion
1984 $
-500
-400
-300
-200
-100
0
+100
Merchandise
Trade
Current
Account
1972
73
74
75
76
77
78
79
1980
81
82
83
84
Year

FIGURE 3

U.S. Petroleum Consumption by Sector, 2000

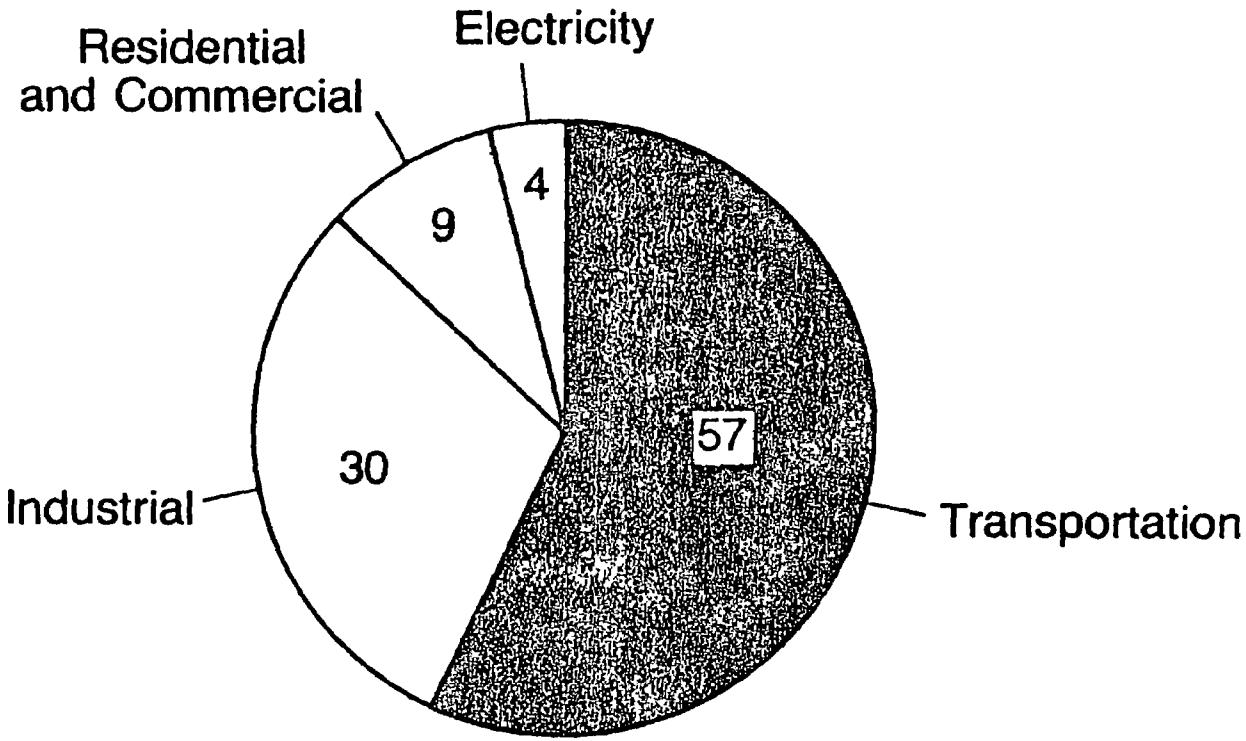


Table 1

EPA Transit Bus Engine Emission Standards
(g/bhp-hr over EPA transient engine test)

	HC	CO	NOx	PM
Current engines	0.5 to 1.0	1 to 5	5 to 9	0.4 to 0.8
1985-1987 standard	1.3	15.5	10.7	none
1988-1990 standard	1.3	15.5	6.0	0.6
1991 and later standard	1.3	15.5	5.0	0.1

Table 2

Recoverable Fossil Fuel Resource Distribution in the United States

Resource	Percentage of Total Recoverable Fossil Fuel Energy*	Percentage of Total Recoverable Fossil Fuel Energy+
Coal	91.2	81.7
Oil Shale	2.8	12.9
Crude Oil	2.2	2.0
Conventional Natural Gas	2.2	2.0
Unconventional Gas	1.6	1.4

*Including only those oil shale resources containing over 30 gallons of oil per ton.
+Including only those oil shale resources containing over 15 gallons of oil per ton.

Table 3

Diesel Bus Engine vs. Chassis Emissions
(EPA transient test procedures)

Pollutant	New Diesel Bus Engines (g/bhp-hr)	In-Use Diesel Bus Chassis (g/mile)
HC	1.51	3.35
CO	3.22	51.9
NOx	6.25	26.1
PM	0.57	5.52

Table 4

New Diesel vs. Methanol Bus Engine Emissions
(g/bhp-hr)

Pollutant	Diesel Bus Engines	MAN Methanol Bus Engine	GM Methanol Bus Engine
PM	0.57	0.04	0.17
NOx	6.25	6.60	2.20
CO	3.22	0.31	-
Organics	1.61	0.68	1.28
HC	1.51	0.001	-
Methanol	0	0.68	1.13
Aldehydes	0.10	0.001	0.15

Table 5

In-Use Diesel vs. Methanol Bus Chassis Emissions
(g/mile)

Pollutant	Diesel Bus Chassis	MAN Methanol Bus Chassis	GM Methanol Bus Chassis
PM	5.52	0.09	1.09
NOx	26.1	13.6	7.90
CO	51.9	0.65	107
Organics	3.88	1.40	120
HC	3.35	0.09	1.15
Methanol	0	1.16	116
Aldehydes	0.53	0.15	2.33

About Cars/Marshall Schuon NYT p36 12/3/89

Engine Adjusts to Use Methanol or Gasoline

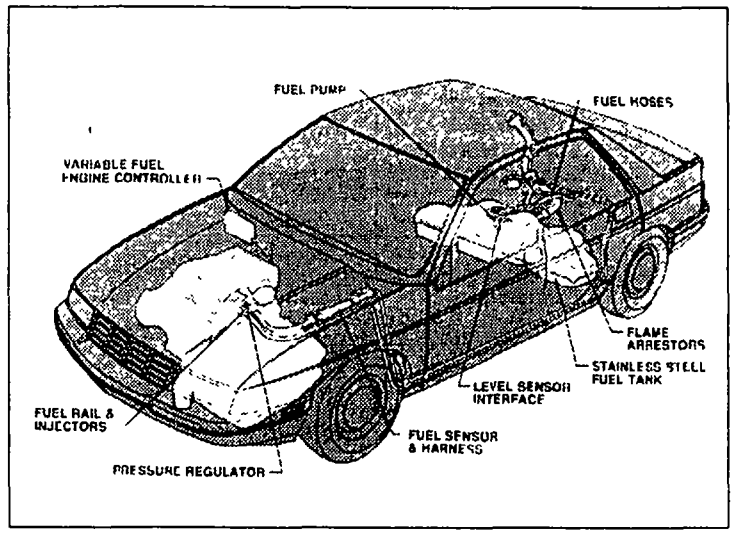
The car looks much like any other black Lumina Euro sedan There is the red stripe along the lower body, the spoiler on the trunk, the molded alloy wheels But there are differences For one thing, there is that outrageous red and white legend on the front doors, the one that screams *Gasoline/Methanol! GM!*

And there are the innards, stainless-steel this and noncorrosive that

The car is a variable-fuel vehicle, one of 2,220 that will go to California in the next two years in a major assault on the tyranny of foreign oil and, perhaps, as a warrior in the battle for cleaner air

Right now, though, the gleaming 1990 Chevy four-door lives in my driveway, and it is an interesting animal Under the hood, there is a 3 1-liter V6, and the engine's thirst is satisfied equally by methanol or by gasoline

That is the meaning of "variable fuel," and the heart of the system is a sensor that detects the amount of methanol or gasoline in the line and sends its message to a computer The computer then alters the engine to operate on what it is being fed



Alcohol-resistant materials allow Chevrolet's variable-fuel vehicle to run on methanol or gasoline. The combustion mixture is regulated by a computer that receives signals from the fuel sensor

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Methanol, a form of alcohol produced from natural gas or from coal, has been getting a lot of attention as a fuel that can supplement domestic supplies in the event of a petroleum cutback, and California is making a big push for that and for an end to pollution But, as always, there are problems

For example, methanol is less volatile than gasoline, which gives it poor starting characteristics in cold weather And it has only about half the energy of gas, meaning that it takes twice as many gallons to get from here to there

Worse, it costs more — on the order of $1 50 a gallon And it is devilishly corrosive

Because of its low volatility, it can also form a flammable mixture in the tank at normal temperatures, and when it burns in an open area under bright sunlight, it has a nearly invisible flame There are safety concerns

But David Dimick, executive engineer of the General Motors advanced engineering staff, believes that the glitches can be worked out, and that the West Coast experiment will be a big step forward

"The State of California intends to buy these cars and to incorporate them into regular fleet use," he said "They will be used by utilities and by government employees, and eventually will find their way into private fleets We have some Chevy Corsicas out there now, and we're learning a lot"

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One of those things is just how corrosive methanol is

The cars' tanks, with built-in flame arrestors, are made of stainless steel There are Teflon hoses, special fuel pumps and anodized fuel-injection systems But Dimick said G M has discovered that even the nickel-plated filler necks were disintegrating And the gas caps were turning to lace "We've had to replace the pipes and the caps with stainless steel," he said

Another difficulty is methanol's electrical conductivity, which has been creating shorts in sender units and other engine components And Dimick said, there have been problems with the fuel injectors themselves

> Methanol is so corrosive that the gas caps were turning to lace.

Then, too, there is methanol's own problem of pollution While it emits fewer hydrocarbons than gasoline, it produces more aldehydes and unburned fuel So the air-quality benefit depends on the degree to which those factors are controlled

"We recognize there's a strong interest in getting the level down," Dimick said, "and our intent is to get significantly lower aldehyde numbers on some of those California cars"

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The Lumina in the driveway, meanwhile, seems to run very well indeed, whether on methanol or on gasoline And it is hard to tell the difference, although the alcohol fuel does seem to make the car feel its oats

That has been proved in testing, Dimick said, and the V6's 135 horsepower jumps by about 7 percent when the car is running on methanol

That fuel, incidentally, is rarely 100 percent alcohol Because of the inherent driveability and cold-start problems, a small amount of gasoline (about 15 percent) is added

While the California cars will have dashboard gauges to indicate the exact percentage of alcohol running through the engine, the gauge is missing on this car and a fill-up with gasoline made the mix only roughly 50-50

The nice thing of course, is that you *can* put any mix of gas or alcohol into the tank and the car will do the rest The bad thing, and one of the major stumbling blocks in the alternative-fuel effort, is that methanol stations are so few and far between

Chevrolet was taking no chances on that count, however The engineers filled the car in Detroit and brought it to New York on a flatbed truck