# COMPARATIVE ANALYSIS OF THE ENVIRONMENTAL IMPACT OF ALTERNATIVE TRANSPORTATION FUELS

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## INTRODUCTION

Emissions from motor vehicles contribute significantly to air pollution problems. Despite new emission standards and advances in motor vehicle emission control technology, many areas in the country are still projected to have air pollution problems in the year 2000 and beyond. It appears unlikely that there will continue to be significant declines in emissions from gasoline and diesel-powered vehicles. This situation has spurred interest in alternative fuels for transportation.

Substituting alternative transportation fuels for gasoline and diesel fuel may improve air quality in the United States. The goal of this paper is to analyze the impact of alternative transportation fuels on attainment of The National Ambient Air Quality Standards for ozone and carbon monoxide (CO). Although cost and other consumer acceptance factors are not analyzed, all the alternative fuels studied are considered feasible for use by the general public. The term "alternative fuel" is used throughout this report to mean any non-gasoline or diesel fuel, including gasoline mixtures.

This report concentrates on light duty applications of alternative fuels, because light-duty vehicles play a much greater role in ozone and CO non-attainment than heavy-duty vehicles. The emphasis in this report is on how methanol, compressed natural gas (CNG), and liquified petroleum gas (LPG) compare with gasoline.

## IMPACT OF ALTERNATIVE FUELS ON ATTAINMENT OF THE NAAQS FOR OZONE

One of the most persistent air quality problems in the U.S. has been the attainment of the NAAQS for ozone. Currently, approximately 90 million people live in areas that have one or more violations of the ambient ozone standard, and a downward trend in ozone levels is not evident. In 1988 there were more ozone violations than in many of the previous years.

Ozone is caused by atmospheric photochemical reactions involving volatile organic compounds (VOCs) and oxides of nitrogen ($NO_x$). Mobile sources account for about half of these emissions. The ozone formation rate is greater at higher ambient temperatures.

VOCs are emitted from mobile sources as either tailpipe or evaporative emissions. Tailpipe emissions occur as a result of incomplete combustion and/or chemical reactions during combustion. $NO_x$ is largely produced by reactions between nitrogen and oxygen at high temperatures.

EPA policy emphasizes that states should control ozone by reducing VOCs rather than $NO_x$ emissions. However, in areas dominated by VOC emissions (i.e., they have a high HC to $NO_x$ ratio in the ambient air) there is some evidence that reducing $NO_x$ emissions, as well as VOCs, helps reduce ozone.

## Impact of Alternative Fuels on Reactive VOC Emissions

VOCs emitted from mobile sources typically are termed hydrocarbons (HCs). In 1988 most (92 percent) of the HC emissions from mobile sources were from light-duty gasoline-powered vehicles (1). Therefore, these vehicles are the target for additional HC controls.

An analysis of VOC emissions impacts must consider both exhaust and evaporative emissions. Furthermore, the photochemical reactivity of these emissions must be considered.

The State of California recently quantified the composite reactivity of emissions from vehicles powered by different fuels. In their study, they speciated emissions for different fuels and calculated the mass-weighted reactivity of the total vehicle emissions. The results of their study are summarized on Table 1 (1). Non-methane VOC emissions from natural gas-powered vehicles are less reactive than those from vehicles powered by other alternative fuels; they are less than half as reactive as non-methane hydrocarbons (NMHC) from gasoline-powered vehicles. Methane emissions were excluded because they have neglible reactivity. VOC emissions from methanol-fueled vehicles include methanol and are estimated to be between 50 and 56 percent as reactive as those from gasoline-powered vehicles. The lower percentage assumes low formaldehyde emission rates (15 mg/mile).

The following discussion compares non-methane VOC emission rates for vehicles powered by different fuels. Exhaust and evaporative emissions rates that are reported in publicly available sources are analyzed.

Reactive VOC Exhaust Emissions for Different Fuels - Reactive VOC emissions from alternative fueled vehicles include non-methane hydrocarbons (NMHCs), methanol, and formaldehyde. Figure 1 summarizes information on NMHC and formaldehyde exhaust emissions from light-duty vehicles burning different fuels. Although a range of values is shown on Figure 1, almost all the emission tests were performed on low-mileage vehicles, so the range may still underestimate in-use emissions. The M100 (100% methanol) numbers are for advanced, dedicated prototypes, while the CNG and LPG numbers are more representative of production dual-fuel vehicles.

For reference purposes, two estimates are presented for VOC exhaust emissions from gasoline-powered vehicles. The high estimate was generated by MOBILE4 (EPA's mobile source emission factor model) for a fleet composed almost entirely of 1981 and newer automobiles. The low estimate for gasoline-powered vehicles equals the exhaust emission standard for 1981 and newer vehicles.

Table 2 summarizes the range of methanol exhaust emissions in grams per mile that were found in the database for M85- and M100-fueled vehicles. Note that the high number (1.6 g/mi) for M85 (85% methanol, 15% gasoline) was a 50,000 mile projection made by EPA (2), so it most likely represents the in-use emission factor in grams per mile. The high value for M100 (1.7 g/mi) is the average of emission test results on vehicles operated on greater than 90 percent methanol (3). If in-use vehicles emit methanol at rates close to the high range shown on Table 2, some ozone impacts, in addition to those from NMHC and formaldehyde emissions, are likely from methanol-fueled vehicles.

Evaporative Emissions for Different Fuels - Evaporative emissions are composed of stationary evaporative losses (hotsoak and diurnal losses), running evaporative losses, and refueling losses. VOC emissions due to fuel evaporation will vary greatly for the different alternative fuels.

Figure 2 shows a comparison of stationary NMHC evaporative losses for different fuels. The database contains information on stationary evaporative losses for vehicles fueled with M85; MOBILE4 was used to estimate evaporative losses from gasoline-powered vehicles. The high value (0.14 g/mi) for M85 shown on Figure 2 is a 50,000 mile in-use projection made by EPA (4). The low value for M85 is based upon test results for two advanced prototype vehicles (5).

Few data are available on the amount of VOC's that is emitted due to running losses or refueling losses for the different alternative fuels. Table 3 shows estimated running and refueling NMHC losses based upon engineering judgment.

Table 4 summarizes the reported range of methanol evaporative emissions while the vehicle is stationary (hot soak and diurnal losses). The high value for M85 (0.37 g/mi) is the 50,000 in-use estimate by EPA (2). The low value (0.02 g/mi) is based on two advanced prototypes tested by the California Air Resource Board (4). Only one test result was available on advanced M100 vehicles (equivalent to 0.12 g/mi) (4).

Total Reactive VOC Emissions from Light-duty Vehicles for Different Fuels - Figure 3 shows estimates of the total exhaust and evaporative reactive VOC emissions from light-duty vehicles during periods when the ambient temperature ranges between 60° and 84°F. Methanol emissions are indicated by the shaded area. Because they have low NMHC emissions in the exhaust and negligible evaporative emission losses, dedicated CNG vehicles are estimated to emit the smallest amount of reactive VOC emissions.

The total emission values for M85 and M100 vehicles include methanol. The totals for M85 are similar to the MOBILE4 estimate for gasoline-powered vehicles, but as discussed earlier M85 vehicle emissions are less reactive than gasoline-powered vehicle emissions. Thus, there may be some ozone benefits for M85, but a clear benefit is not evident. M100-powered vehicles are estimated to have greater ozone benefits than M85 because they appear to emit much less NMHC. Dedicated LPG vehicles may have similar benefits to M100 vehicles; LPG may result in greater NMHC emissions than M100 but M100 will result in substantial methanol emissions.

Dual-fuel LPG and CNG vehicles will emit much greater amounts of VOCs than dedicated LPG and CNG vehicles because of evaporative NMHC losses.

$NO_x$ Emissions for Different Alternative Fuels

The other precursor component in the atmospheric formation of ozone is oxides of nitrogen ($NO_x$). In 1988 about two-thirds of the mobile source $NO_x$ emissions came from light-duty gasoline-powered vehicles.

Figure 4 compares estimated emissions from light-duty vehicles burning different alternative fuels with emissions from light-duty gasoline-powered vehicles. Unlike the case with NMHC emissions, MOBILE4 estimates of $NO_x$ emissions from 1981 and newer light-duty vehicles are identical to the $NO_x$ standard.

Considering that gasoline-powered vehicles can meet much more stringent emission levels than the Federal $NO_x$ standard, none of the alternative fuels appears to offer clear advantages in reducing $NO_x$ emissions from light-duty vehicles. Emission rates lower than the MOBILE4 estimates were observed for all the fuels; however, emission rates equal to or higher than the MOBILE4 estimates also were observed for most of the fuels. One can conclude that light-duty vehicles can be designed to burn alternative fuels such as CNG, LPG, or methanol and meet emission levels achievable by gasoline-powered vehicles; but it appears unlikely that large reductions are possible. Dual-fuel CNG vehicles are expected to emit about the same amount of $NO_x$ as dedicated CNG vehicles with similar $NO_x$ emission controls.

## IMPACT OF ALTERNATIVE FUELS ON ATTAINMENT OF THE NAAQS FOR CARBON MONOXIDE

Exceedances of the NAAQS for carbon monoxide (CO) are less widespread than exceedances of the ozone standard. There has been a significant downward trend in ambient CO concentrations, but several tough CO attainment problems remain. Areas with extreme ambient conditions, such as Alaska and Colorado, are not projected to attain the CO standard without additional controls.

About 80 percent of the nationwide CO inventory is from mobile sources. And most (91 percent) of the mobile source CO emissions are from light-duty gasoline-powered vehicles (1).

Figure 5 shows the range of CO emissions that were observed for light-duty vehicles powered by different fuels. Two estimates of gasoline-powered CO emissions are provided as a reference. One is the MOBILE4 estimate for 1981 and newer vehicles, the other is the CO emission standard for 1981 and newer vehicles.

CNG-powered light-duty vehicles appear to have lower CO emissions than vehicles powered by other fuels. These levels were achieved by vehicles with both advanced emission controls and with no emission controls. These data indicate that CO emissions from CNG-powered vehicles are likely to be very low in actual use, because CO emission levels are less sensitive to vehicle technology or tampering. It is possible to run a CNG engine rich (too much fuel) which greatly increases CO emissions, but these cases should be identified in most inspection/maintenance programs or preventive maintenance checks.

LPG vehicle emissions are higher than CNG vehicle emissions, but are lower than the CO standard for 1981 and newer light-duty vehicles. When M85 and M100 vehicle emissions are compared with the CO emission standard, there appears to be no clear advantage for those fuels. The data are not adequate to project a CO emission value comparable to the MOBILE4 estimate for M85- and M100-powered vehicles. Because most of the emission tests were performed on low-mileage, well-maintained vehicles, it is likely that actual in-use emissions for those fuels would be much higher.

CONCLUSIONS

Impact of Alternative Fuels on Attainment of the NAAQS for Ozone - Efforts to attain the NAAQS for ozone would be enhanced if vehicle fleets in non-attainment areas consumed certain alternative fuels instead of gasoline. Dedicated CNG vehicles appear to have the greatest ozone benefits. LPG and M100 vehicles also offer significant ozone benefits. However, dual-fuel CNG or LPG vehicles and M85 vehicles (vehicles designed to burn mixtures of 85 percent methanol and 15 percent gasoline) may not be much better than gasoline vehicles. The primary reason for this is that evaporative volatile organic compounds (VOCs) emissions from storage of gasoline in the vehicle greatly increase their overall contribution to ozone formation.

This conclusion assumes that each fuel will displace a similar amount of gasoline. It does not consider consumer acceptance or infra-structure issues that will impact the market penetration of an alternative fuel.

Impact of Alternative Fuels on Attainment of the NAAQS for Carbon Monoxide (CO) - Both dedicated and dual-fuel CNG vehicles emit much less CO than gasoline-powered vehicles, so their use will help an area attain the CO NAAQS. LPG vehicles also appear to produce lower amount of CO than gasoline-powered vehicles, but they emit greater amounts than CNG-powered vehicles. Available data are not adequate to project the impact of methanol-fueled vehicles on CO. Preliminary data show that methanol-powered vehicles (both M85 and M100) will emit much more CO than CNG-powered vehicles.

REFERENCES


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3. Data Base on Emissions from Methanol Fueled Vehicles. U. S. Environmental Protection Agency, Ann Arbor, MI, 1989.

4. Gold, M. D. and C. E. Moulis. Emission Factor Data Base for Prototype Light-Duty Methanol Vehicles. In: Methanol -- Promise and Problems. International Fuels and Lubricants Meeting and Exposition, Toronto, Ontario, 1987.

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TABLE 1. *COMPARISON OF EXHAUST[a] REACTIVITY FOR DIFFERENT FUELS

| Fuel Type | Reactivity Factor[b] |
|---|---|
| Gasoline | 1 |
| M85 | .56 |
| M85-Low HCHO | .5 |
| LPG (Dual-Fueled) | .85 |
| LPG (Dedicatad) | .67 |
| CNG (Dual-Fueled) | .45 |
| CNG (Dedicated) | .36 |

[a]Emissions include NMHC, formaldehyde, and methanol, but exclude methane.

[b]Relative to gasoline.

Source: Reference 40.

TABLE 2. METHANOL EXHAUST EMISSIONS FROM 1981 AND NEWER AUTOMOBILES BURNING METHANOL

| Fuel | Methanol (g/mi) (Range in database) |
|---|---|
| M85 | 0.14[a] - 1.6[b] |
| M100 | 0.33[c] - 1.7[d] |

[a]Average of 3 lean-burn vehicles (42-CARB 88).

[b]50,000 mile projection (2-EPA 87).

[c]One advanced prototype vehicle (1-EPA 89).

[d]Average of emission test results on vehicles fueled with greater than 90 percent methanol (5-EPA 89).

TABLE 3. ESTIMATED NMHC RUNNING LOSS AND REFUELING EMISSIONS 1981+ LIGHT-DUTY VEHICLES - SUMMER

| | | Running Loss (g/mi) 60 - 84°F | Running Loss (g/mi) 80 - 95°F | Refueling Loss (g/mi) |
|---|---|---|---|---|
| FLEET LDGV (MOBILE4) | | 0.28 | 0.59 | 0.25 |
| M85 | | 0.19[a] | 0.38[a] | 0.17 |
| M100 | | 0 | 0 | 0 |
| CNG - DUAL FUEL | 0.14/0.1 | 0.23[c] | 0.41[b] | 0.05[c] |
| CNG - DEDICATED | | 0 | 0 | 0 |
| LPG - DEDICATED[f] | | 0[d] | 0[d] | -[e] |

[a]Determined by multiplying MOBILE4 gasoline projection by ratio of projected M85 evap/MOBILE4 evap

[b]Assumed to be equal to MOBILE4 emissions with RVP = 8.0 psi

[c]Assumes 80% natural gas, 20% gasoline operation.

[d]Assumes no fugitive emissions.

[e]Small amount of refueling losses. Data not available.

[f]LPG - Dual-fuel will be similar to CNG dual-fuel.

LDGV = Light duty gasoline vehicles

NOTE No emission standard has been established for running losses, originally assumed to be zero

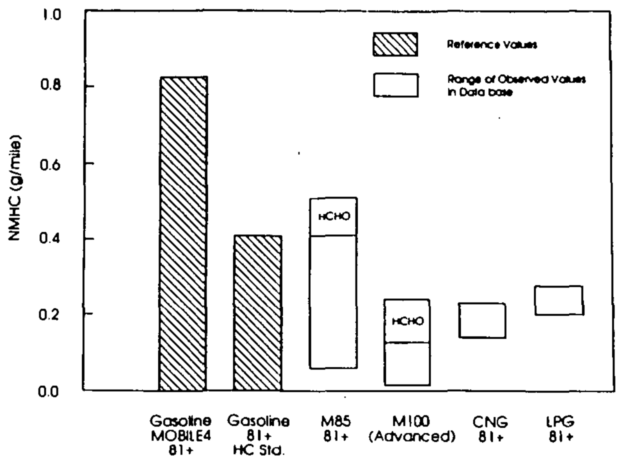
TABLE 4. EVAPORATIVE METHANOL EMISSIONS FROM 1981 AND NEWER METHANOL-FUELED VEHICLES

| Fuel | Methanol (g/mi) |
|---|---|
| M85 | 0.02[a]-0.37[b] |
| M100 | 0.12[c] |

[a]Two advanced prototypes (42-CARB 88).

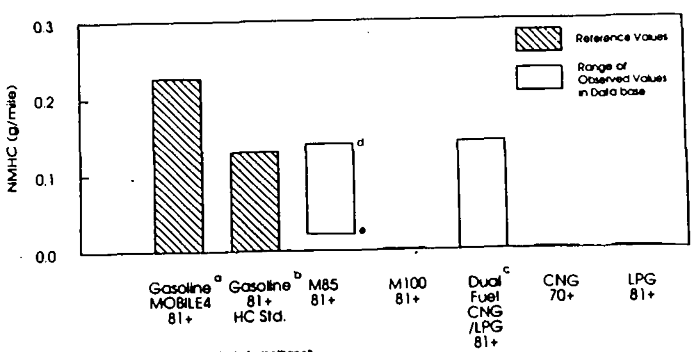
[b]50,000 mile in-use projection (2-EPA 87).

[c]One test (2-EPA 87).



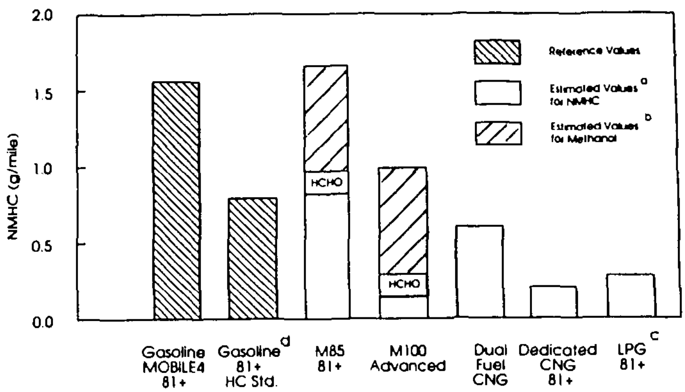

81+ = Closed Loop, Three-way Catalyst
Advanced = Prototype, under development

Figure 1. NMHC Exhaust Emissions from Light-duty Vehicles



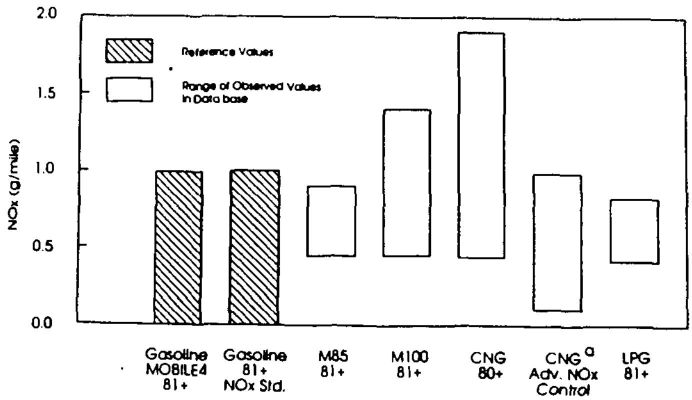

a Stationary losses (Does not include methanol).
b 9.0 psi RVP
c Assumed to be the same as MOBILE4, gasoline (RVP = 8.0psi).
d 50,000 mile projection by EPA(7-EPA 87)
e Based on 2 advanced prototype vehicles (42-CARB 88)
81+ = With Evaporative Emissions Controls, certified to meet 2 gram evaporative standard (approximately 0.14 g/mi)

Figure 2. NMHC Evaporative Emissions[a] from Light-duty Vehicles




a Values are based on high observed emission levels in data base.
b HC Equivalent
c Assumes no fugitive emissions and dedicated application. Dual fuel LPG will be like dual-fuel CNG
d Assumes no running losses.
HCHO Formaldehyde

Figure 3. Estimated Total VOC from Light-duty Vehicles (Exhaust plus Evaporative Losses) during Average Summer Weather (60°-84°F)




a. Speculative, no test data available.
81+ = Closed Loop, Three-way Catalyst
80+ = Oxygen Catalyst, or Three-way Catalyst
Adv NOx Control = Fast burn, Stoichometric or Lean burn

Figure 4. Estimated $NO_x$ Emissions from Light-duty Vehicles

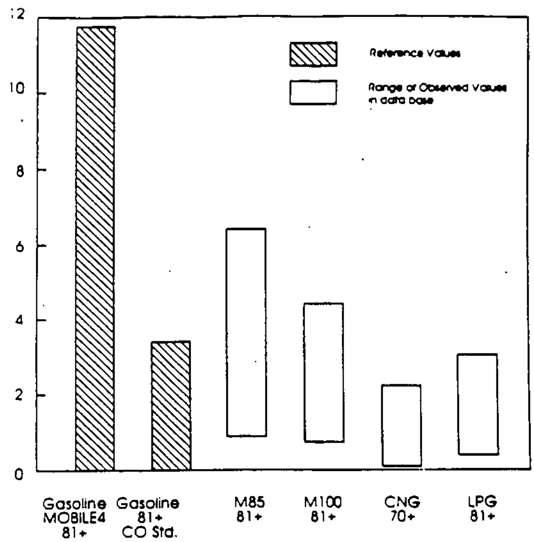



Figure 5. CO Emissions from Light-duty Vehicles