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## Environmental and Energy Policy Implications for Reformulated Gasoline and Alternative Fuels

Thomas J. Lareau

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THOMAS J. LAREAU\*

INTRODUCTION

Alternative fuels and reformulated gasoline are important components of current environmental and energy policy. The issue of future transportation fuels is important to citizens because of its effect on energy security and air quality. The issue is also important to those companies who invest large sums in finding, producing, and delivering transportation fuels. While today's transportation fuels are derived mostly from oil,<sup>1</sup> the petroleum industry also produces liquid petroleum gases (LPG), one alternative to gasoline, in refineries and gas processing plants.<sup>2</sup> Recently, some petroleum companies have purchased large natural gas producing properties. These investments have not yet yielded a significant return because the price of natural gas remains depressed.<sup>3</sup> Compressed natural gas (CNG), another alternative transportation fuel, might open a new market for natural gas, so some oil companies are actively pursuing its development. Currently, the industry stake in methanol, a third alternative, is minimal.

This article evaluates the environmental and energy impacts of future alternatives to conventional gasoline. The analysis is based, in part, on several research reports that I and others have written at the American Petroleum Institute (API) over the last three years.<sup>4</sup> The first section examines the reasons for the considerable policy interest in reformulated gasoline and alternative fuels. The second section compares the technical and economic advantages and disadvantages of each fuel. The third section focuses on the vehicle emissions problem in our cities and summarizes recent

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\* Senior Economist, American Petroleum Institute. The views expressed are those of the author and not necessarily those of the American Petroleum Institute or its member companies.

1. Petroleum provided 21.6 of 22.2 quadrillion BTU of transportation energy in 1989. U.S. OFFICE OF TECHNOLOGY ASSESSMENT, ENERGY TECHNOLOGY CHOICES: SHAPING OUR FUTURE 122 (1991).

2. ENERGY INFORMATION ADMINISTRATION, U.S. DEPT. OF ENERGY, PETROLEUM SUPPLY ANNUAL 25 (1989).

3. See generally Carlson, Heinkel, Morehouse, Tropmann & Wagner, *Background on the Natural Gas Industry*, NAT. GAS MONTHLY (Sept. 1991).

4. Research reports and articles include: R. ANDERSON, T. LAREAU & R. WOLLSTADT, THE ECONOMICS OF GASOLINE ETHANOL BLENDS (Am. Petroleum Inst. Research Study No. 045, 1988); R. JONES & T. LAREAU, THE COST OF ALCOHOL FUEL MANDATES: TRANSPORTATION, MARKETING, DISTRIBUTION, FIRE AND SAFETY, AND MEASUREMENT (Am. Petroleum Inst. Discussion Paper No. 059, 1989); Lareau, *The Economics of Alternative Fuel Use: Substituting Methanol for Gasoline*, CONTEMP. POL. ISSUES, Oct. 1990, at 138; T. LAREAU, D. LAX, P. MARTINO, & W. BUSH, METHANOL VEHICLE EMISSIONS (Am. Petroleum Inst. Publication No. 4262, 1990); R. JONES, THE ECONOMICS OF ALTERNATIVE FUEL USE: COMPRESSED NATURAL GAS AS A VEHICLE FUEL (Am. Petroleum Inst. Research Paper No. 056, 1990).

research on reformulated gasoline. The final section contrasts market methods with mandate methods of determining the future mix of transportation fuels. I have chosen to exclude those alternatives that require substantial technical progress for commercial success. These include biomass and electric or hydrogen vehicles.

### I. POLICY INTEREST IN REFORMULATED GASOLINE AND ALTERNATIVE FUELS

There are two fundamental policy issues responsible for the active interest in alternative fuels and reformulated gasoline. The first is the concern for national security resulting from dependence on imported crude oil. I believe, however, that the so-called "energy security problem" is parochial and largely irrelevant. While in the past, the U.S. was confronted with a serious price risk and even political extortion, that situation has changed significantly. Today, the foreign producer faces as much risk as consumers. The events of the 1980s showed producers that high oil prices have long-term repercussions.<sup>5</sup> In response to high prices, consuming countries invested in conservation equipment and developed alternatives to oil. As demand declined, high prices could not be sustained since many OPEC members found that long-run revenues were not maximized at these high prices. OPEC is not powerless, but under most foreseeable conditions, the real risk is not unaffordable oil prices, but rather the possibility of occasional supply disruptions.

Prices can increase rapidly when supplies are reduced, as occurred after Iraq's invasion of Kuwait.<sup>6</sup> However, a short-term disruption of supply is effectively countered by the Strategic Petroleum Reserve. The fraction of oil imported has little economic significance in a disruption. The price we pay for *all* oil is the international price, regardless of how much we import.<sup>7</sup> Thus, the disruption cost due to a supply interruption is independent of the percentage of oil imported. This fact is frequently not understood. Alternative fuels might possess some energy security value, but the value is in diversifying energy sources, not in reducing imports of oil. Reducing imports is desirable, but only if in doing so we reduce total energy expenditures. That is, any replacement for foreign oil should be less expensive.

But energy security is not the most important reason for interest in alternative fuels today. Rather, environmental concerns dominate legislative and regulatory debate about transportation fuels. The two major environ-

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5. See generally E. PORTER, *WORLD PETROLEUM SUPPLY: HISTORY, PROSPECTS, AND POLICY ISSUES* (Am. Petroleum Inst. Discussion Paper No. 066, 1991).

6. See generally D. NORMAN & D. SHIN, *PRICE ADJUSTMENT IN GASOLINE & HEATING OIL MARKETS* (Am. Petroleum Inst. Research Study No. 060, 1991).

7. See generally D. MONTGOMERY & J. SWEENEY, *MANDATE FOR ALTERNATIVE FUELS: A POLICY ANALYSIS* (Aug. 1991) (submitted to Am. Petroleum Inst. by Charles River Associates).

mental concerns are the urban ozone problem and the greenhouse problem.

The Clean Air Act Amendments (CAAA) of 1990<sup>8</sup> established three new requirements for vehicles and fuels. First, there are tighter vehicle standards.<sup>9</sup> The new vehicle standard for volatile organic compound (VOC) emissions (sometimes called hydrocarbon emissions) decreases from the current standard of 0.41 grams/mile (gm/mi) to 0.25 gm/mi in 1994 (Tier 1), and possibly to 0.125 gm/mi in 2003 (Tier 2). The nitrogen oxide (NO<sub>x</sub>) standard tightens from 1.0 gm/mi currently to 0.4 gm/mi in 1994, and possibly to 0.2 gm/mi in 2003. California's vehicle standards are even more stringent,<sup>10</sup> and other states may adopt these tighter standards.

Second, the use of oxygenated and reformulated fuel is required.<sup>11</sup> Oxygenated gasoline is gasoline blended with either ethanol, an alcohol, MTBE, an ether, or possibly ETBE, an ether similar to MTBE. All add oxygen to the fuel. The resulting leaner fuel mixture reduces carbon monoxide (CO) emissions. Oxygenated fuel is required in forty areas that do not meet the National Ambient Air Quality Standard (these areas are called non-attainment areas) for CO, starting in the fall of 1992.<sup>12</sup> Reformulated gasoline, which also must include an oxygenate, is mandated in nine of the most severe ozone non-attainment cities in 1995. Reformulated gasoline is required to reduce hydrocarbon emissions by at least 15 percent. Other ozone non-attainment areas can petition to be included in the reformulated gasoline program (called "opt-in") and many are expected to do so. If opt-in occurs to the full extent permitted in the CAAA, about half the nation would use reformulated gasoline.<sup>13</sup>

The third requirement of the CAAA is that alternative fuel vehicles must be purchased by vehicle fleet owners in 22 ozone non-attainment areas.<sup>14</sup> By 1998, 30 percent of all vehicles purchased for fleets must use an alternative fuel. By 1999, this requirement will increase to 50 percent, and by the year 2000, to 70 percent.

The Alternative Motor Fuel Act of 1988<sup>15</sup> also could affect the demand for alternative fuels. This law provides Corporate Average Fleet Efficiency

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8. Pub. L. No. 101-549, 104 Stat. 2399 (1990) (codified as amended in scattered sections of 42 U.S.C.).

9. Pub. L. No. 101-549, § 203, 104 Stat. 2424 (1990) (codified at 42 U.S.C. § 7521).

10. 42 U.S.C.A. § 7521 (West 1983 & Supp. 1991). *See also* CALIFORNIA AIR RESOURCES BOARD, PROPOSED REGULATIONS FOR LOW EMISSION VEHICLES AND CLEAN FUELS 20 (1990).

11. 42 U.S.C.A. § 7545 (West 1983 & Supp. 1991).

12. *Id.*

13. In an API study, Russell Jones and I questioned whether oxygenate supply would be sufficient to market this much reformulated gasoline by 1995. R. JONES & T. LAREAU, MEETING THE OXYGENATE REQUIREMENTS OF THE 1990 CLEAN AIR ACT AMENDMENTS (Am. Petroleum Inst. Research Study No. 058, 1991).

14. Pub. L. No. 101-549, § 246, 104 Stat. 2511 (1990) (codified at 42 U.S.C. §§ 7581-7590). Alternative fuel is defined to include reformulated gasoline. *Id.*

15. Pub. L. No. 100-494, 102 Stat. 2441 (1989) (codified at scattered sections of 42 U.S.C. and 15 U.S.C.).

(CAFE) credits for alternative fuel vehicles, giving a strong incentive to the vehicle manufacturers to produce either dedicated alternative fuel vehicles or dual fuel vehicles. Methanol and gasoline dual fuel vehicles are of interest for their perceived environmental benefits in California, where hundreds of these vehicles operate in a demonstration program. CAFE credits could provide sufficient benefit to vehicle manufacturers to sell many methanol vehicles in California.

Finally, the California Low Emission Vehicle program<sup>16</sup> also could have a substantial impact on the demand for alternative fuels and reformulated gasoline. The California program consists of four vehicle classes: (1) Transitional Low Emitting Vehicles (TLEVs) must meet a 0.125 gm/mi VOC standard; (2) Low Emission Vehicles (LEVs) must meet a 0.075 gm/mi VOC and 0.2 gm/mi NO<sub>x</sub> standard; (3) Ultra Low Emitting Vehicles (ULEVs) must meet a 0.04 gm/mi VOC standard; and (4) Zero Emitting Vehicles (ZEVs) cannot emit any VOCs, NO<sub>x</sub> or CO. ZEVs probably would be electric powered. Some combination of alternative fuels, reformulated gasoline and better emission control equipment will be necessary in California to attain these levels. These same vehicle standards are under serious consideration in other states.

## II. REFORMULATED GASOLINE VERSUS ALTERNATIVE FUELS

How the federal and California standards will be met is somewhat uncertain. The CAAA and California requirements seemingly are fuel neutral. A better perspective on the prospects for the various alternative fuels is obtained by comparing and contrasting the physical properties, the environmental and energy security impacts, and the cost of reformulated gasoline and alternative fuels. One caveat is necessary. This discussion is intended to illustrate relative impacts based on current state of the art technologies.<sup>17</sup> Future technological advances could alter these relationships.

Table 1 summarizes the basic physical characteristics of the fuels. Perhaps the most important characteristic is energy density. Gasoline's higher density relative to the alternative fuels means less of it is necessary to travel a mile.<sup>18</sup> This leads to a cost advantage for gasoline and storage and range disadvantages for the alternatives. However, the alternative fuels have an octane advantage, which can improve performance.<sup>19</sup> The bottom half of Table 1 compares vehicle performance using reformulated gasoline, which is equivalent to conventional gasoline, to performance of vehicles using LPG,

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16. See California Air Resources Board, *supra* note 10.

17. All tables appear at the end of this article.

18. For example, it takes about 1.8 gallons of methanol to travel the same distance as 1.0 gallon of gasoline. AM. PETROLEUM INST. PUBLICATION NO. 4261, (1980), ALCOHOLS AND ETHERS: A TECHNICAL ASSESSMENT OF THEIR APPLICATION AS FUELS AND FUEL COMPONENTS 5.

19. *Id.* at 4-5.

CNG, and methanol. Today, over 300,000 LPG vehicles are operating in the U.S.<sup>20</sup> Few CNG vehicles operate in the U.S., but other countries, such as Italy and New Zealand, have many CNG vehicles operating.<sup>21</sup>

Relative to gasoline vehicles, optimized LPG or CNG vehicles have similar power and acceleration. However, their driving range will be less than gasoline powered vehicles because the fuel has a lower energy density. This disadvantage is greatest for CNG, which requires heavy and bulky pressurized fuel tanks. There are other disadvantages for CNG, particularly the need for compressors to refuel the vehicles.

Methanol with its high octane can be run in high compression engines, providing a bit more power and peppier performance compared to gasoline. However, because methanol is less dense than gasoline, the range of a methanol vehicle is less than a comparable gasoline vehicle. This means that a methanol vehicle will either need a bigger fuel tank or its owner will have to refuel more often. A further disadvantage of methanol is that it is corrosive. This requires either changing motor oil more frequently or using special oils yet to be developed. Finally, methanol has cold start problems in northern climates.

Table 2 shows three energy security metrics: (1) oil imports; (2) other energy imports;<sup>22</sup> and (3) supply limits. Reformulated gasoline would have only a modest effect on oil and other energy imports. At least ten percent of reformulated gasoline would consist of an oxygenate with the remaining ninety percent or less consisting of traditional refined products. Since part of the oxygenate used will be made domestically, oil imports could be reduced slightly. There are no long-term reformulated gasoline supply limits, though converting the nation to reformulated gasoline would take many years.

There could be a significant decrease in oil imports if LPG or CNG were substituted for gasoline. But in both cases, decreased oil imports would be offset partially by increases in other energy imports. If large volumes of LPG or CNG were used, natural gas, LPG or liquified natural gas (LNG) would be imported. The U.S. supply of LPG is limited,<sup>23</sup> and most of that supply is committed to high valued use in the chemical and other industries. Right now, there is an excess supply of the natural gas needed to make CNG.<sup>24</sup> Further, many believe that there are substantial gas resources yet to be developed. So initially, CNG could absorb the excess supply, replacing oil imports. Eventually though, the price of natural gas in the

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20. U.S. Department of Energy, ASSESSMENT OF COSTS & BENEFITS OF FLEXIBLE & ALTERNATIVE FUEL USE IN THE U.S. TRANSPORTATION SECTOR, PROGRESS REPORT ONE: CONTENT AND ANALYTICAL FRAMEWORK D-2 (1988).

21. *Id.*

22. While greater use of alternative fuels decreases oil imports, other energy imports frequently increase.

23. *Id.* at A-4.

24. Carlson *et al.*, *supra* note 3.

United States would rise, and we would have to import natural gas (or products made from it) from other countries, where natural gas could be produced for less. In that case, oil dependence would be exchanged for natural gas dependence.

Substituting methanol for gasoline also could reduce oil imports. However, the savings would be offset partly by an increase in methanol imports. Methanol can be made from many things (including coal), but right now the cheapest feedstock is natural gas in other countries. There are no significant supply limits with methanol, though it would take many years to expand methanol production capacity to supply fuel markets with large volumes.<sup>25</sup>

Table 3 summarizes the environmental impacts of reformulated gasoline and alternative fuels relative to today's conventional gasoline. The first two rows show VOCs and NO<sub>x</sub>, which are the precursors of ozone, the major constituent of smog. The third row shows CO. While CO is a problem in many cities today, CO non-attainment will diminish over time as newer lower emission vehicles phase out older vehicles in the fleet. The last row shows carbon dioxide (CO<sub>2</sub>), which is one of the gases associated with the greenhouse effect.

All the alternative fuels and reformulated gasoline reduce VOCs. The greatest reduction comes from the use of CNG. The impact on NO<sub>x</sub> is mixed and subject to some controversy, with some tests showing slightly higher NO<sub>x</sub> emissions for LPG and CNG. LPG and CNG result in much larger reductions of CO than reformulated gasoline or methanol, but there are reductions in all cases. The change in CO<sub>2</sub> is not dramatic for any of these fuels. LPG and CNG reduce CO<sub>2</sub> slightly. Reformulated gasoline and methanol would have roughly similar impacts on the formation of CO<sub>2</sub> as today's gasoline.

Table 4 provides an approximation of the relative cost of the alternative fuels and reformulated gasoline assuming 1990s technologies and large volume sales. Phase I federal reformulated gasoline, to be introduced in 1995, is estimated to cost about 5 cents more per gallon to manufacture than today's gasoline. The cost of more severely reformulated gasoline is speculative. That cost is dependent upon the EPA's specification of Phase II reformulated gas to be introduced in the year 2000. If this gasoline is similar to California's 1996 severely reformulated gasoline, the increased cost of future reformulated gasoline could be in excess of 20 cents per gallon. The distribution and marketing costs of reformulated gasoline would not change.

LPG and CNG fuels are substantially less expensive than gasoline, but LPG and CNG vehicles are more expensive than gasoline vehicles. The higher cost of a CNG vehicle is the result of the pressurized fuel system. LPG is pressurized also, but not as much as CNG. The distribution and marketing costs would be slightly higher for LPG. CNG, however, would be much

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25. T. LAREAU, *THE ECONOMICS OF ALTERNATIVE FUEL USE: SUBSTITUTING METHANOL FOR GASOLINE 2* (Am. Petroleum Inst. Research Study No. 047, 1989).

more expensive to market, given the high cost of powerful compressors needed at service stations.

Methanol, primarily a chemical feedstock, sells for about 40 cents per gallon now.<sup>26</sup> This is roughly 10 cents a gallon more than wholesale gasoline.<sup>27</sup> However, the cost of methanol as a fuel would be different. To pay for a new plant to produce methanol fuel overseas, where its natural gas feedstock would be cheaper, methanol would have to sell for 36 cents more than today's wholesale gasoline, on a gasoline gallon equivalent basis. Distribution and marketing costs are also higher because pipeline capacity must be expanded to deliver a lower energy density fuel.

In sum, when fuel, vehicle, and distribution and marketing costs are totalled, reformulated gasoline is less costly than methanol and CNG. LPG, in contrast, might be cost competitive with reformulated gasoline.

Table 5 summarizes the energy, environmental and cost trade-offs. Reformulated gasoline does not have much impact on energy security. It does, however, benefit the environment. Also, in contrast to CNG and methanol, there is only a modest increase in cost. LPG also has a modest beneficial effect on the environment. CNG has a very favorable impact on the environment and can improve energy security, but CNG is much more expensive. Methanol is inferior on one or more criteria relative to reformulated gasoline, LPG and CNG, and is not obviously superior to any other alternative on any criteria. Given the assumptions underlying Table 5, LPG, CNG, and reformulated gasoline are preferred to methanol. It is difficult to pick an obvious winner among reformulated gasoline, LPG, and CNG. That judgment requires a cost-benefit analysis to determine the value of the energy security and environmental benefits of these fuels.

If the energy security impact is questionable, as I have argued, then the attractiveness of reformulated gasoline and alternative fuels comes from their potential to reduce mobile source emissions.

### III. URBAN POLLUTION AND REFORMULATED GASOLINES

This section discusses the mobile source problem and recent industry research. The automobile companies and the major petroleum companies are conducting a joint study to find the best fuels and vehicles.<sup>28</sup> Much has been learned, and though it is not easy to summarize, some idea of the complexity of tradeoffs among fuel parameters, vehicle vintage, and types of emissions can be shown. The initial Auto-Oil work on gasoline recipes led

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26. U.S. Spot Market, New Fuels Report (Alcohol Week, Washington, D.C.) Dec. 9, 1991, at 16 (generally available in any Fall 1991 issue).

27. Equivalency calculated on basis of cost per mile using 1.8 factor. *See supra* note 18.

28. The Auto-Oil Air Quality Improvement Research Program was initiated in the fall of 1989 and subsequently has published a series of technical bulletins, including: AUTO-OIL AIR QUALITY IMPROVEMENT RESEARCH PROGRAM TECHNICAL BULLETIN NO. 1: INITIAL MASS EXHAUST EMISSIONS RESULTS FROM REFORMULATED GASOLINES (1990).

to a variety of cross-cutting emissions impacts. This research focused on changes in aromatics, oxygenates, olefins, and the distillation curve (T90 point) on VOCs, CO, and NO<sub>x</sub> (see Figure 1). As expected, the VOCs and NO<sub>x</sub> change in opposite directions for any change in one gasoline constituent. Since both are precursors of ozone, this is a problem. It is hard to see from this figure what should be done, though reducing the T90 point seems attractive. Further, the situation is far more complicated when several gasoline constituents are changed at once, when evaporative emissions are added to exhaust emissions, and when vehicle emission control equipment changes. The most recent research explored reducing the sulfur content of gasoline, and this unambiguously provides a benefit.<sup>29</sup>

Substantial progress has been made and most petroleum companies are confident that they will be able to produce lower emission fuels in the future.

Using speciated emissions reductions from Auto-Oil vehicle tests and EPA inventory models, air quality models are used to project ozone reduction benefits. The results are sometimes fascinating. Consider the simulation results in Table 6 for New York City. This table shows that in one episode in 1985, the ozone concentration was 357 parts per billion (ppb). The ozone standard is 120 ppb. In the year 2010, the model projects a peak ozone level of about 200 ppb. Both stationary and mobile source controls contribute to this reduced ozone level. In 1985, automobiles contributed 117 ppb out the 357 ppb. In 2010, the automobile contribution declines to 17 ppb. That is a very small portion. What is the explanation for this result? One factor is the replacement of older higher emission vehicles. Today's vehicles are significantly cleaner than older vehicles and the new standards reduce these emissions even more. So, by the year 2010 the automobiles are not expected to contribute much to the ozone problem. In fact, both EPA's and California's inventory models show that the vehicle contribution to the ozone problem will go down from the roughly 50 percent range in today's air sheds to about 20 percent in some air basins in ten to twenty years.<sup>30</sup>

The important assumption in this projection is that new low emitting vehicles continue to operate cleanly after they are sold. One recent discovery in the mobile source emissions area is that a large part of emissions comes from failures of emissions control equipment on both old and new cars. These faulty vehicles often have emissions per vehicle equivalent to 10 or more properly operating cars. Thus, a major policy concern is the identification and control of malfunctioning vehicles. If this is accomplished, then the new vehicles and fuels will be more effective in reducing the ozone problem over the next 20 years.

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29. AUTO-OIL AIR QUALITY IMPROVEMENT RESEARCH PROGRAM, TECHNICAL BULLETIN NO. 2: EFFECTS OF FUEL SULFUR LEVELS ON MASS EXHAUST EMISSIONS (1991).

30. See generally Chang & Rudy, *5 Urban Air Quality Impact of Methanol Fueled Vehicles Compared to Gasoline Fueled Vehicles*, in METHANOL AS AN ALTERNATIVE FUEL CHOICE: AN ASSESSMENT 97 (W. Kohl ed., 1990).

#### IV. POLICIES DRIVING THE FUTURE MIX OF FUELS.

Perhaps the most important aspect of the reformulated gasoline and alternative fuel issue is whether to depend on markets or centralized control to change the transportation fuel mix. Some have suggested mandating the use of alternative fuels by the year 2000.<sup>31</sup> Usually the requirement is that 10, 20, or even 30 percent of the fuel pool must be made from non-petroleum feedstocks. Often these proposals include a requirement to produce the fuel domestically.

These proposals are a good way to manufacture white elephants. Alternative fuel mandates are reminiscent of the synfuels program 10 years ago, when the government tried to force a technology that was not ready for commercialization. The result was billions of dollars spent on large industrial facilities that could not produce competitively in the marketplace.

Alternatively, evolutionary change with market processes is possible. The CAAA and the emission performance standards in California are generally consistent with that kind of approach.

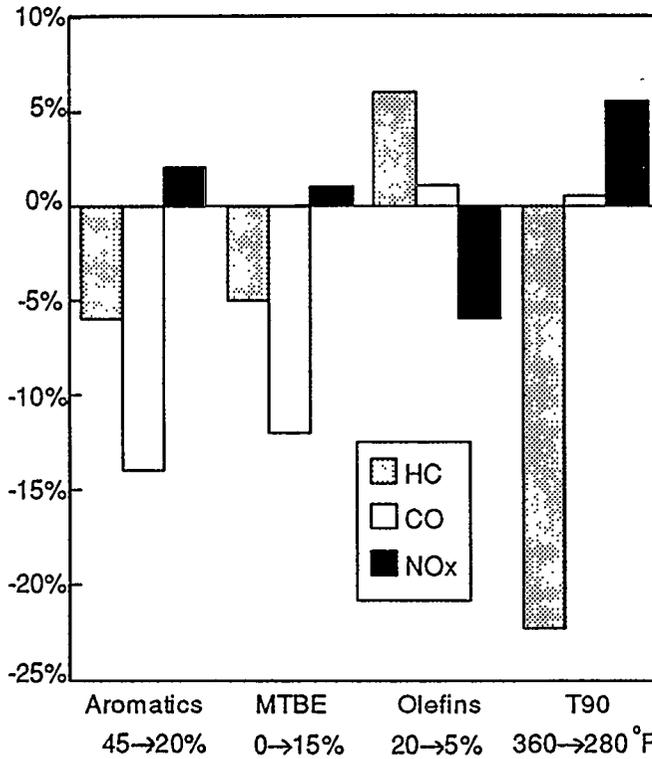
#### CONCLUSION

In summary, alternative fuels may seem attractive, but, notwithstanding the evolutionary shift to reformulated gasoline, large scale commercialization is premature. Recognizing that the best future transportation fuel mix is unclear, there are still some worthwhile ideas to pursue. These include joint government and private sector alternative fueled vehicle demonstration projects, similar to the methanol effort in California. Introducing alternative fuel vehicles into fleets first, as the Clean Air Act provides, is also worthwhile. Alternative fueled vehicles are better suited for fleet applications than for the general consumer, since it is easier for fleets to accommodate specialized refueling or maintenance requirements. The recently legislated changes in the Clean Air Act should be given a chance to demonstrate their effectiveness before embarking on more radical proposals that have a high risk of doing more damage than good.

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31. See, e.g., S. 716, 102d Cong., 1st Sess., 137 Cong. Rec. S3806 (daily ed. Mar. 21, 1991) (Jeffords Bill).

Figure 1  
Fuel Effects on  
Auto Exhaust Emissions  
(Current Vehicles - 1989)



Source: AUTO-OIL AIR QUALITY IMPROVEMENT RESEARCH PROGRAM TECHNICAL BULLETIN No. 1 (1990).

**Table 1****Physical Properties of Reformulated Gasoline and Alternative Fuels**

	Reformulated Gasoline	LPG	CNG	Methanol
Fuel <sup>a</sup> .				
Energy Density (Btu/gal)	110,000	82,000	22,800	56,800
Octane (R+M/2)	87 - 93	104	120	99
Vehicle <sup>b</sup> .				
Power/Acceleration	=	=	=	+
Range	=	-	--	-
Other <sup>c</sup>	=	-	-	-

Sources: AM. PETROLEUM INST., PUB. NO. 4261, ALCOHOLS AND ETHERS: A TECHNICAL ASSESSMENT OF THEIR APPLICATION AS FUELS AND FUEL COMPONENTS (1990); U.S. DEPT. OF ENERGY, DOE/PE-0080, ASSESSMENT OF COSTS AND BENEFITS OF FLEXIBLE & ALTERNATIVE FUEL USE IN THE U.S. TRANSPORTATION SECTOR, PROGRESS REPORT ONE: CONTENT AND ANALYTICAL FRAMEWORK (1988). Author's judgment used in qualitative comparisons.

## Notes:

- a. Conventional gasoline has energy density of approximately 114,000 Btu/gal.
- b. Symbols represent vehicle performance relative to conventional gasoline, where:  
"++" is much better; "+" is marginally better; "=" represents no appreciable difference; "-" is marginally inferior; and "--" is significantly inferior.
- c. Includes refueling convenience, maintenance, and cold start capability.

**Table 2**  
**Energy Security Impact Summary**

	Reformulated Gasoline	LPG	CNG	Methanol
Oil Imports	down slightly	down	down	down (but not barrel for barrel)
Other Energy Imports	up slightly	up slightly	up, eventually	up
Supply Limits	No	Yes	No	No

Sources: R. JONES, THE ECONOMICS OF ALTERNATIVE FUEL USE: COMPRESSED NATURAL GAS AS A VEHICLE FUEL (Am. Petroleum Inst. Research Study No. 056, 1990); T. LAREAU, THE ECONOMICS OF ALTERNATIVE FUEL USE: SUBSTITUTING METHANOL FOR GASOLINE (Am. Petroleum Inst. Research Study No. 047, 1989).

**Table 3**  
**Environmental Impact Summary**

	Reformulated Gasoline	LPG	CNG	Methanol
VOC	lower	lower	much lower	lower
NO <sub>x</sub>	similar	slightly higher	slightly higher	similar
CO	lower	much lower	much lower	lower
CO <sub>2</sub>	similar	slightly lower	slightly lower	similar

Sources: See U.S. DEPT. OF ENERGY *supra* Table 1; JONES *supra* Table 2; LAREAU *supra* Table 2; T. Chang, R. Hammerle, S. Japar, and I. Salmeen, *Alternative Transportation Fuels and Air Quality*, 25 ENVIR. SCI. AND TECH. (No. 7 1991).

**Table 4**  
**Cost Summary <sup>a</sup>**  
**(dollars per gasoline equivalent gallon**  
**relative to today's conventional gasoline)**

	Reformulated Gasoline <sup>b</sup>	LPG	CNG	Methanol
Fuel	0.05 - 0.20+	-0.17	-0.33	0.36
Vehicle	0	0.32	0.43	0.13
Distribution & Marketing	0	0.07	0.27	0.12
	0.05 - 0.20+	0.22	0.37	0.61

Sources: U.S. DEPT. OF ENERGY, *supra* Table 1; JONES, *supra* Table 2; LAREAU, *supra* Table 2; NAT'L RES. COUNCIL, *FUELS TO DRIVE OUR FUTURE* (1990); R. JONES AND T. LAREAU, *THE COST OF ALCOHOL FUEL MANDATES: TRANSPORTATION, MARKETING, DISTRIBUTION, FIRE AND SAFETY, AND MEASUREMENT* (Am. Petroleum Inst. Discussion Paper No. 059, 1989); and analysis of R. Jones and T. Lareau.

Notes:

a. All costs shown on an energy equivalent basis relative to conventional gasoline and vehicles. Based on review of literature, a CNG vehicle would cost \$1000 more than a conventional gasoline vehicle; a LPG vehicle, \$750 more; and a methanol vehicle, \$300 more. Fuel costs, assuming large market volume, are: \$0.55/gal. for methanol; \$0.40/gal. for LPG; and \$2.50/mcf. for CNG.

b. Lower bound is cost of 1995 Phase I Federal reformulated gasoline. Upper bound is cost of severely reformulated gasoline similar to California Phase II reformulated gasoline.

**Table 5**  
**Summary of Tradeoffs**

	Reformulated Gasoline	LPG	CNG	Methanol
Energy Security	=	=	+	=
Environment	+	+	++	+
Cost	-	-	--	--

Sources: *See supra* Tables 2, 3, and 4. Author's judgment used in qualitative comparisons.

Note: Symbol definitions are the same as those in Table 1.

**Table 6**  
**Peak Ozone in Los Angeles**  
**(Parts per Billion)**

	1985	2010
All Sources	357	197
Automotive Contribution		
with Base Line Gasoline	117	--
with Industry Average Gasoline	--	17
with Reformulated Gasoline	--	13

Source: AUTO-OIL AIR QUALITY IMPROVEMENT RESEARCH PROGRAM, TECHNICAL BULLETIN NO. 3: AIR QUALITY MODELING RESULTS FOR REFORMULATED GASOLINES IN YEAR 2005/2010 (1991).

Note: Federal ozone standard is 120 parts per billion.