APPENDIX A

Reformulated Gasoline

Introduction

The reformulation of gasoline (changing physical and chemical characteristics to reduce vehicle emissions) is currently being pursued by both the Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) as a way of reducing vehicle carbon monoxide (CO), toxics, and volatile organic compound (VOC) emissions. In response to specific provisions contained in Title II of the Clean Air Act Amendments of 1990 (CAAA), EPA is implementing a reformulated gasoline program to go into effect in nine cities in 1995. Requirements will tighten in the year 2000, and States with ozone problems can opt into this program for additional areas. California, with the worst air quality problems in the country, is developing a similar but separate set of reformulation requirements, with an accelerated timetable and greater stringency.

The Federal Government (the Department of Energy and EPA) and California are also leading the development and implementation of alternative-fuel programs based on methanol, natural gas, LP Gas, and electric-powered motor vehicles. These "clean fuel" alternatives are expected both to improve air quality and to reduce petroleum use. However, because these alternative fuels can only be used in specially designed or modified vehicles, the transition to their use will occur only as the vehicle population is gradually replaced. Therefore, reformulated gasoline is an alternative to both current gasoline and these alternative fuels. It will provide a means to reduce emissions from conventional automobiles and oil use (through the addition of non-petroleum-based components), while alternative-fuel technologies and markets are under development.

The combined effect of the EPA program, the California reformulation program, and the pressure created on States by the other provisions of the CAAA to reduce emissions is expected to result in most gasoline being reformulated by the year 2000. Based on 1989 consumption, it is anticipated that 22 percent of U.S. gasoline demand is in the nine specified reformulated-gasoline cities. If other eligible regions choose to opt in, that volume would increase to about 55 percent of U.S. gasoline consumption. In this context, reformulated gasoline is the appropriate comparative benchmark in terms of cost-efficiency and performance for alternative fuels.

Reformulated Gasoline Provisions of the Clean Air Act Amendments

The CAAA define "reformulated" gasoline using two methods: specific gasoline characteristics and performance standards. Starting in 1995, benzene content of gasoline may not exceed one percent by volume. Oxygen content must equal or exceed two percent by weight and detergents must be present in amounts large enough to prevent the accumulation of deposits in engines or vehicle fuel-supply systems. There is also a ban on lead or heavy metals. In addition to these characteristic requirements, performance goals also must be met.

The emissions performance standards are set in relation to emissions from "baseline" vehicles using "baseline" gasoline. The CAAA define a baseline vehicle as one that is representative of model year 1990. Summer baseline gasoline is specified by the CAAA and winter baseline gasoline is determined by EPA.

Three performance requirements apply. Nitrogen oxides (NO_x) emissions from baseline vehicles using reformulated gasoline may not exceed NO_x emissions from the same vehicles using baseline gasoline. Aggregate VOC emissions from baseline vehicles during the high-ozone season of the year should be 15 percent below emissions from the same vehicles using baseline gasoline. Starting in the year 2000, the 15-percent reduction is increased to 25 percent, unless 25 percent is technologically infeasible, in which case EPA can lower the requirement to 20 percent.

The performance goals for toxics are approached in a similar manner, comparing the total emissions of four specific chemicals from baseline vehicles using baseline gasoline to baseline vehicles using reformulated gasoline. Toxic reductions are effective year-round, with toxic emissions from baseline vehicles using reformulated gasoline required to be 15 percent below the toxic emissions from the same vehicles using baseline gasoline. Beginning in the year 2000, 15 percent will be increased to 25 percent if it is technologically feasible. Again, EPA has the discretion to lower this to a 20-percent reduction if necessary.

California's Reformulated Gasoline Activities

On September 28, 1990, CARB approved regulations for California Phase I reformulated gasoline. Beginning on January 1, 1992, no gasoline may be sold or supplied with a Reid vapor pressure (RVP) above 7.8 pounds per square inch (psi) to designated air basins during specified high-ozone time periods, and all California gasoline must meet a sulfur limit of 300 parts per million. In addition, all gasoline sold in California must be lead free and must contain detergents to control deposits in the engine and fuel lines.

CARB is currently in the process of developing requirements for Phase II California-reformulated gasoline. If CARB adopts the proposed rules, beginning January 1, 1996, reformulated gasoline in California will have to meet requirements similar to the Federal requirements for the year 2000. It will have to meet specific stringent limits on RVP, sulfur and olefin content, and the T–50 and T–90 distillation points (temperatures at which 50 percent and 90 percent of gasoline components boil).

Current Commercial "Reformulated" Gasolines

In the past 2 years, many refiners have begun marketing their own versions of "reformulated" gasoline. For the most part, "reformulated" gasolines have been gasolines with reduced volatility and some added oxygen in the form of methyl tertiary-butyl ether (MTBE) or ethanol. Atlantic Richfield Company (ARCO), a west coast gasoline marketer, has received much attention for several of the emissions-reducing gasolines it has created, and they are representative of what parameters are important in this context.

ARCO has developed three reformulated products, EC–1, EC–Premium, and EC–X. EC–1 went on sale in September 1989 for use in cars that run on leaded gasoline. In September 1990, EC–Premium entered the market as a low-polluting high octane premium gasoline. EC–X is the latest gasoline proposed by ARCO and has very low RVP, sulfur, and olefin contents and a high oxygen content. ARCO believes that EC–X will meet EPA's emission standard and parameter requirements for reformulated gasoline in the year 2000. According to ARCO, EC–X, as compared to conventional gasoline, is reputed to produce 28 percent fewer hydrocarbon tailpipe emissions, 36 percent fewer evaporative emissions, and 26 percent fewer NO_x emissions. In addition, ARCO claims a 25-percent reduction in CO emissions and a 47-percent reduction in emissions of toxic compounds.

Status of Federal Rulemaking

As of this writing (September, 1991), EPA is in the process of developing the rules governing reformulated gasoline, including what characteristics will meet the CAAA's requirements, how gasoline formulations are approved, and how the rules will be enforced. EPA is working through a negotiation with the interested parties. The latest EPA proposal envisions simple compliance specification in 1995 through 1997 with more flexibility and complexity (allowing tradeoffs between parameters) after 1997. For 1995 reformulated gasoline, EPA is concentrating on a few parameters for emission control: RVP, benzene, and oxygen. EPA currently believes that the initial 15-percent reduction of VOC's will be met almost entirely by RVP reduction. Volatility requirements already in place will limit RVP to 8.7 psi in "Class C" areas and to 7.8 psi in "Class B" areas. Using the current version of EPA's emissions model, Mobile–4, EPA has decided that lowering

RVP to 8.1 psi and 7.2 psi will result, respectively, in a VOC reduction of 15 percent in Class C and Class B areas. The 15-percent toxic reduction will also be determined with an emissions' model, and compliance is dominated by benzene control and RVP control, which indirectly cuts toxics (because the toxics are a subset of the vehicle's VOC emissions, and benzene is the dominant toxic).

It is known that other gasoline parameters (olefin content, aromatic content, sulfur content, distillation) influence the performance of NO_x, VOC, and toxics, and with the implementation of the "complex" configuration model for 1997, refiners will be allowed to trade off among all these parameters when trying to achieve the CAAA's performance goals. EPA is still in the process of deciding how these parameters should be traded to determine whether a gasoline qualifies as reformulated. The multiyear auto-oil study, sponsored jointly by auto manufacturers and refiners, is just starting to produce detailed data on what fuel components are key in reducing emissions. EPA is preparing to delay making a "complex" gasoline certification model until much more information is available.

Likely Reformulation Characteristics in the Year 2000 and Beyond

Current emissions testing indicates that the key parameters to control are sulfur, olefins, aromatics, T-90, benzene, and oxygen. In addition, by the year 2000, EPA will likely require the full 25-percent reduction of both VOC and toxic emissions, because it now appears technically possible to meet those standards. The VOC reduction will likely be met through further volatility reductions and reductions in olefins, sulfur, and T-90. Toxics reductions will emphasize volatility, aromatic content, benzene content, and oxygenate type.

California is proceeding to prescribe gasoline quality limits that look as though they meet or exceed the Federal program needs in year 2000. CARB's pending proposal for 1996 severely restricts sulfur and olefin content, and it also places limits on the T-50, T-90, and the drivability index (an aggregate measure of the gasoline distillation characteristics).

Comparison of Current and Future Gasolines

Table A-1 shows the physical and chemical characteristics of current gasoline and the likely characteristics of gasolines in the year 2000, based on the status of ongoing research and rulemaking programs of EPA and CARB. The principal nonpetroleum components that will be used in reformulated gasoline are oxygenates. Federal reformulated gasoline is required to contain at least 2.0 percent oxygen by weight. Oxygenates that could be used include ethers such as MTBE, ethyl tertiary-butyl ether (ETBE), and tertiary-amyl-methyl-ether, or alcohols such as methanol and ethanol. Refiners will use principally MTBE and ethanol, because they are the only oxygenates currently used in significant amounts. Oxygenates will be needed not only for the reformulated gasoline program, which is in effect year-round, but also at higher levels for the CO-control program, primarily in the winter in about 41 cities. MTBE seems a logical choice for a summer oxygenate, because it has a lower volatility. Initial auto and oil data also indicate that MTBE can probably be used in concentrations up to 2.7 percent without causing an increase in NO_x. In fact, the current EPA proposal for certifying reformulated gasoline favors MTBE, because it can be used at higher concentrations than ethanol without being considered a cause of NO_x increase. Refiners may also find it difficult to use ethanol in the summer. It has a high blending RVP of 17 to 22 psi, making it difficult to blend and still meet summer RVP levels. All other changes in gasoline characteristics are expected to occur through changes in refining methods—equipment, operations, and gasoline blending practices.

Table A–1. Characteristics of Gasoline and Various Reformulations

Characteristic	1990[a] Industry Average Gasoline	1990[b] CAAA Summer Baseline Gasoline	1990[b] CAAA Winter Baseline Gasoline	1992[c] California Phase I Reformulated Gasoline	1995[d] Federal Reformulated Gasoline	1996[e] California Phase II Reformulated Gasoline	2000[f] Federal Reformulated Gasoline
RVP, psi[g]	8.6	8.7	12.9	7.8 max	8.1 or 7.2 max	7.0 max	?
Oxygen %	0	0	0.52	N/S	2.0[h] avg	2.0[h] avg	2.0
Benzene %	1.6	1.53	1.64	N/S	1.0 max	1.0 max	1.0
Aromatics %	34.4	32.0	26.3	N/S	25.0 max[i]	25.0 max	?
Sulfur, ppm	349	339	340	N/S	No increase	30.0 max	?
Olefins %	9.7	9.2	11.9	N/S	No increase	5.0 max	?
T-90, °F	323	330	332	N/S	No increase	300.0 max	?
T-50, °F	213	218	199	N/S	N/S	200 max	?
Drivability Index	N/S	N/S	N/S	N/S	N/S	1,100 max	?

N/S = Not Specified.

[a] *New Fuels Report*, July 15, 1991.

[b] EPA Draft Rules Federal Register Notice 56 FR 31239.

[c] Title 13, California Code of Regulations, Section 2251.5.

[d] EPA Draft Rules Federal Register Notice 56 FR 31187-88 (Some averaging of most parameters allowed with some tightening of requirements).

[e] August 1991, CARB proposed amendments to Title 13, California Code of Regulations, Sections 2261.1-2261.7.

[f] EPA Draft Rules Federal Register Notice 56 FR 31187-88.

[g] These RVP limits apply during summer ozone season only.

[h] 1.5% minimum and 2.1% maximum except for MTBE, which has a 2.7% maximum.

[i] Aromatic limit in the Act is not binding if toxic limit is met.

Anticipated Refinery Changes To Produce Reformulated Gasoline

Producing these reformulations of gasoline will require changes to existing refineries. Because individual refineries vary significantly, not all refineries will need to make all changes listed below, and some changes may occur that are not listed here. The most likely changes are as follows:

- To meet RVP requirements, refiners will have to stop blending butanes into summer gasoline entirely, and some will need to adjust distillation operations to remove butanes and pentanes from other blendstocks. Butane is currently used as an inexpensive octane-enhancing component, but because it has a very high RVP, around 60 psi, it will need to be eliminated. The unused butane can be burned, used as a chemical feedstock for production of MTBE, or chemically converted to a low RVP component.

- Reformer severity will be reduced to reduce the aromatic and benzene content of its output. The reformer has served as an octane source, because lead was removed from gasoline, but the addition of oxygenates such as MTBE will boost octane ratings and allow less severity of reformer operations. Certain benzene precursors may also be removed from the reformer feed.

- Alkylation operations will increase. Alkylate is a low-toxic, low-reactivity, high-octane blendstock with a very low vapor pressure.

- Refiners will need to install hydrotreaters to remove the sulfur from feedstocks and, thereby, from gasoline. Hydrogen plants and sulfur recovery units will also be needed to support hydrotreating operations.

- Many refineries will also install or expand their own MTBE products to meet oxygenate needs. Furthermore, to cut olefins and create oxygenates, refiners may reoptimize catalytic cracking operations to produce large amounts of small olefins, then react those with methanol or ethanol to produce low RVP ethers.

Cost Impact of Gasoline Reformulation

It is difficult to assess the long-term cost effect of these dramatic changes to gasoline. Final parameters, options to average and trade credits, and the number of markets to be served are not set. In addition, each refinery will face different challenges, and the leading oxygenates are produced and sold in radically different world markets. These uncertainties preclude the development of a definitive cost analysis, but based on the analysis completed to date by industry and government, an incremental cost of 5 to 15 cents per gallon over the cost of conventional gasoline for 1995 and 10 to 20 cents per gallon for the year 2000 is likely.

APPENDIX B

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APPENDIX C

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