University of California, Santa Barbara

The Role of Oxygenated Fuel in California Air Quality

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0. Abstract

Motivated by growing public concern over the contamination of California's groundwater resources with MTBE, and growing public alarm over the contamination's contingent health effects, we conduct a cost benefit analysis of California's statewide use of three gasoline formulations meeting California Reformulated Gasoline, Phase II requirements. These formulations are MTBE-oxygenated gasoline (currently the dominant formulation in California), ethanol-oxygenated gasoline, and a non-oxygenated blend of gasoline. These formulations are compared to a baseline of conventional gasoline, along several cost-benefit categories. The categories most influential on the outcome are human health costs, fuel increase costs, mileage decrease costs, and costs associated with groundwater contamination from gasoline. We conclude that the formulation containing MTBE is the least cost effective, while the non-oxygenated blend is the most cost effective.

Based on these results, we advocate a phase-out of MTBE for California. The phase out should be implemented in an economically efficient way; it should be gradual, over a period of six years, and should consider geographic differences in air quality. We recommend the continuation of voluntary accelerated vehicle retirement programs which remove older, higher-polluting cars from the road. Additionally, we advocate policies that provide for the support of continued advances of vehicle technology, such as improvements in catalytic converters and computer monitored combustion control systems. We suggest that lawmakers establish vehicle emission goals, backed by incentives or penalties, while still allowing for flexibility in how these goals are attained.

1. Executive Summary

Since 1996, gasoline sold in California has contained significant amounts of MTBE to meet oxygen content requirements mandated by the California Air Resources Board, a state agency. The goal of the mandate was to bring California into compliance with the federal Clean Air Act (an pursuant amendments), specifically with respect to the pollutants carbon monoxide and ozone. Recently, however, concern over MTBE contamination of drinking water supplies has raised the question of whether using MTBE is the best choice for California, and ultimately if gasoline formulations in general are an effective strategy for addressing the state's air quality woes.

To answer this first question, we conduct a cost benefit analysis of the statewide use of three gasoline formulations meeting California Reformulated Gasoline, Phase II requirements. These formulations are MTBE-oxygenated gasoline (currently the dominant formulation in California), ethanol-oxygenated gasoline, and a non-oxygenated blend of gasoline. These formulations are compared to a baseline of conventional gasoline, along several cost-benefit categories. Some of the costs and benefits may only be estimated with a degree of uncertainty, so some of our estimates span a range of values.

We conclude that the MTBE-oxygenated gasoline is the least cost-effective option for California's economy. This conclusion is primarily the consequence of MTBE's high direct costs (i.e., fuel price increases and mileage decreases) coupled with the high costs of treatment that the contamination of drinking water supplies has necessitated. The most cost-effective option is the non-oxygenated blend. The dollar value estimates for each option along each cost-benefit category are given in Table 1, and are graphically summarized in Figure 1.

Given the costs associated with the statewide use of MTBE-oxygenated gasoline, we propose a new course of action for California regarding MTBE and fuel formulations in general. We propose a policy through which California can discontinue MTBE's use. This policy recognizes regional differences in air quality as well as the importance of market mechanisms in achieving economic efficiency. This policy classifies each of California's counties into one of three zones based on their carbon monoxide and ozone attainment status.

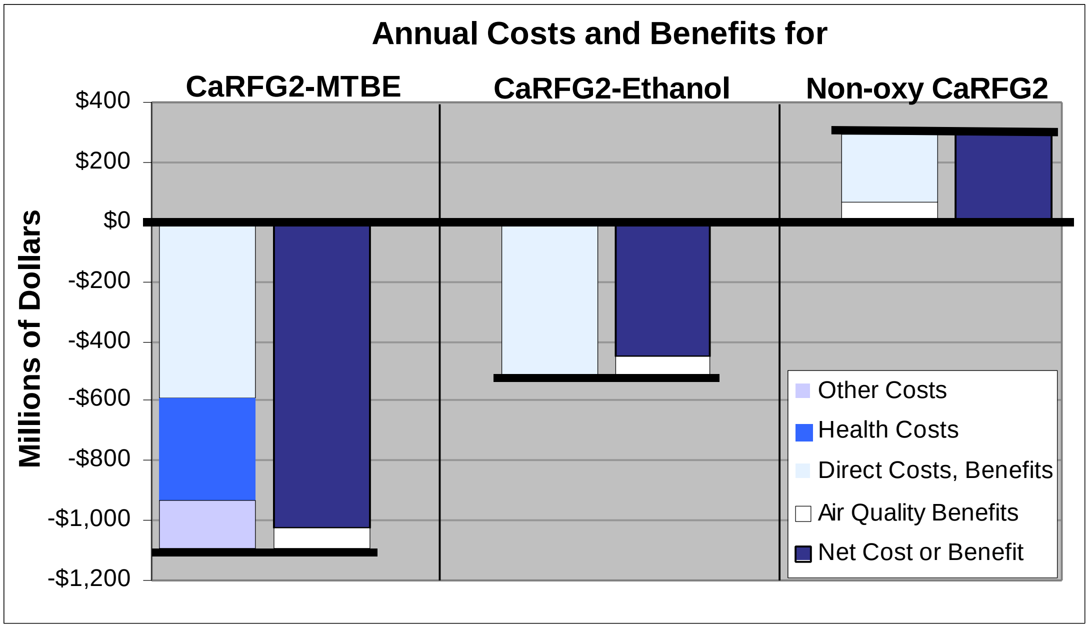

Figure 1. Summary of annualized cost benefit analysis of fuel alternatives, using low estimates for costs and high estimates for benefits. Dark bars represent the net cost or benefit for each alternative (i.e. the difference between the total costs and total benefits)

We propose an immediate ban on the use of MTBE for zones in attainment with federal air quality standards. Oxygenated fuels will still be required in zones that are in non-attainment for both ozone and carbon monoxide. Oxygenated fuels will be optional for zones in attainment for carbon monoxide but not ozone, and refiners selling in these zones may opt to sell gasoline meeting less stringent standards by paying a fee whose proceeds support alternative air quality improvement measures. The use of MTBE as a gasoline oxygenate may only continue in those zones which allow its use for a maximum of six years.

In contrast to modest gains in vehicle emissions resulting from improved gasoline formulations, much larger reductions in vehicle emissions have been achieved by advances of vehicle technology, such as improvements in catalytic converters and computer monitored combustion control systems. Continued progress in these emissions control technologies promises to have a greater effect on California air quality in the long run. Voluntary accelerated vehicle retirement programs, which promote retirement of cars with older technology and higher emissions, can expedite the removal of inferior technology from

California's auto fleet, resulting in better air quality in the shorter term. We advocate advances in vehicle technology, such as improvements in catalytic converters and computer-monitored combustion control systems.

	Fuel with MTBE	Fuel with Ethanol	Non-oxy Fuel
Air Quality Benefits	**$2** to **$66**	**$2** to **$66**	**$2** to **$66**
Health Costs			
air quality damages	($27) to $0	($200) to ($3)	N.S.
water treatment	($1,480) to ($340)	N.S.	($10) to ($1)
alternate water supplies	($30) to ($1)	N.S.	N.S.
Direct Costs			
fuel price increase	($970) to ($280)	($610) to ($220)	($280) to $280
fuel efficiency decrease	($400) to ($310)	($580) to ($290)	$150 to $230
Other Costs			
water monitoring costs	($4) to ($2)	N.S.	N.S.
recreational costs	($340) to ($230)	N.S.	N.S.
ecosystem damages	N.S.	N.S.	N.S.
Costs Subtotal	**($3,251)** to **($1,163)**	**($1,390)** to **($513)**	**($140)** to **$509**
Net Benefit (or Cost)	**($3,249)** to **($1,097)**	**($1,388)** to **($447)**	**($138)** to **$575**

All costs and benefits are expressed in millions of dollars per year. "N.S." stands for "Not significant"

Table 1. Annualized Cost Benefit Analysis of Fuel Alternatives.

We consider a tax-based means of raising funds to clean up water supplies contaminated with MTBE, discussed in Appendix A.

Despite the high costs of using MTBE, its continued ubiquitous presence in California results not from economic forces, but from the government's requirement that gasoline contain a certain amount of oxygenate. Although policy makers surely had good intentions when mandating this requirement, it has become apparent that this command-and-control measure is not in the best interests of the people of California. We caution lawmakers against hastily embracing such restrictive policies based on incomplete information, hoping to find a panacea. Rather, we urge lawmakers to establish emission goals, backed by incentives or penalties, while still allowing for flexibility in how these goals are attained.

2. Introduction

Poor air quality has plagued California for over half a century, beginning with the first recognized episodes of smog in Los Angeles during the summer of 1943. Originally, the main culprits of poor air quality were suspected to be stationary industrial sources, but with the increased urban growth and general population boom following World War II, more and more evidence pointed toward motor vehicles as a substantial contributor to poor air quality in the Golden State (CARB, 1998c). In 1959 California first attempted to control automobile pollution by requiring the Department of Public Health to establish air quality standards and controls for motor vehicle emissions (CARB, 1998c).

Ever since that time, California has been at the forefront of the struggle for clean air. California was the first state to adopt standards for both auto tailpipe emissions, in 1966, and ambient air quality, in 1969 (CARB, 1998c). Furthermore, recognizing that vehicle technology plays a significant role in reducing automotive pollution, California was the first state to require catalytic converters on all new cars sold in the state beginning in 1975 (CARB, 1998c). The battle has been protracted, however, due to the fact that California is at the same time the most populous and the most productive state in the nation, accounting for 12% of the population (U.S. Census Bureau, 1999) and 13% of the gross national product (U.S. Bureau of Economic Analysis, 1999).

California has never been completely in compliance with the National Ambient Air Quality Standards (NAAQS) established by the Federal Clean Air Act of 1970 (42 U.S.C. 7409). The 1990 amendments to the Clean Air Act required that any area not in attainment with the NAAQS could only sell gasoline meeting the specifications of Federal Reformulated Gasoline (RFG). In 1991, the California Air Resources Board (CARB) reached an agreement with U.S. Environmental Protection Agency allowing California to implement sales of California Reformulated Gasoline instead of Federal RFG (see Table 2).

As a result, in 1996 CARB mandated the statewide sale of gasoline meeting the specifications of California Reformulated Gasoline, Phase 2 (CaRFG2). These specifications require, among other things, that any gasoline sold in California must contain at least 1.8% oxygen by weight, in order to produce more complete combustion and therefore fewer harmful emissions. By far the most common oxygenate added to California gasoline is methyl tert-butyl ether, commonly known as MTBE.

The adoption of statewide CaRFG2 use in California has decreased harmful automobile emissions, improving air quality (Koshland et al., 1998). Despite the benefits resulting from these more stringent CaRFG2 specifications, MTBE's role in this success is questioned (Koshland et al., 1998). In fact, MTBE has severely contaminated drinking water reserves, forcing communities to undertake costly clean up procedures or to procure alternative water supplies. This dichotomy raises a question as to whether the benefits of using MTBE as a gasoline oxygenate outweigh its costs. Faced with this question, the California Legislature passed SB 521, commissioning a cost benefit analysis of the use of MTBE as a gasoline oxygenate in California. As a national leader in air quality management and the largest consumer of gasoline among the 50 states, California's policy action regarding MTBE will be closely followed by the rest of the country.

This document provides answers to some of the Legislature's questions by systematically analyzing the costs and benefits of using MTBE-oxygenated gasoline compared to other gasoline formulation alternatives. It concludes by recommending further policy actions to ensure that California moves toward its goal of cleaner air in a prudent, efficient manner.

3. Discussion of Project Objectives and their Significance

The use of MTBE in California has fostered growing public alarm. As the extent of water contamination is discovered, and as questions of public health arise, California citizens are becoming increasingly concerned about the safety of their water sources. In the face of public outcry and legal challenges, the California Legislature has called for an analysis of both the costs and benefits of using MTBE. In 1998, funded by Senate Bill 521, we, along with Arturo Keller and Linda Fernandez, conducted a Cost Benefit Analysis (CBA) investigating several fuel formulation scenarios, including a formulation with MTBE. This document summarizes and discusses the results of the Keller, et al. (1998a) study, and continues on to discuss specific policy actions for improving California air quality.

MTBE Contamination of Water Supplies

MTBE's use as a gasoline additive has caused considerable public concern regarding groundwater and surface water contamination, including contamination of public drinking water supplies. The U.S. EPA has set a drinking water advisory of 20-40 ug/L MTBE while the State of California has set a state drinking water interim action level of 35 ug/L. However, the California State legislature has called for instituting both primary and secondary drinking water standards. The California Department of Health Services has set a 5 ug/L secondary standard based on taste and odor thresholds and a 14ug/L primary standard as a public health goal. These standards were set in response to a high level of contamination in California's water resources and in response to public concern over health hazards of MTBE.

MTBE contamination has been detected throughout California's surface water and groundwater resources, frequently at levels above 5 ug/L. The California Department of Health Services sampled 16% of California's drinking water systems, and detected MTBE contamination in 3.5% of all drinking water systems sampled (CAL-CDHS, 1998). The contamination is more widespread in groundwater monitoring wells, 34% of which tested positive for MTBE contamination (Happel et al., 1998). A major source of groundwater contamination is believed to be leaking pipelines and underground fuel tanks (LUFTs). A 1998 survey of 236 sampled LUFT sites found that 78% were contaminated with levels of MTBE greater than 5ug/L (Happel et al., 1998).

MTBE contamination varies on a regional scale. MTBE at concentrations greater than 35 ug/L have been detected in both Santa Monica and Lake Tahoe. In Santa Monica, seven wells that supply 49% of Santa Monica’s drinking water were closed due to contamination of greater than 35 ug/L MTBE (Happel et al., 1998). Wells have also been closed for the same reason in South Lake Tahoe.

Public Health Hazards

The presence of MTBE contamination in drinking water supplies has increased public exposure to MTBE and public concern over potential health hazards. Both acute and chronic effects of MTBE exposure have been examined. Acute effects include headache, nausea, vomiting, burning sensations in the nose and mouth, dizziness, eye irritation and other symptoms (Froines et al., 1998). Subjects exposed to 75 ppm MTBE in air experienced irritation of mucous membranes as well as mood altering effects (Riihimaki et al., 1998). Leikauf et al. suggested that combustion byproducts of MTBE could exacerbate asthma symptoms. There is evidence that residential proximity to streets with heavy traffic is associated with greater prevalence of asthma in children, but again no studies are available that link this increase with MTBE or its combustion byproducts (Leikauf et al., 1995).

Chronic effects of MTBE exposure may include neurotoxicity, reproductive and developmental effects and carcinogenicity. There is evidence that MTBE is distributed to the central nervous system (CNS), and that upon exposure, MTBE can produce CNS depression including the symptoms of headache, dizziness, nausea and disorientation. These effects are reversible on cessation of exposure (Hakkola et al., 1997). Although maternal and fetal effects are present at doses of 2500 ppm MTBE or greater in animal studies, adequate epidemiological studies of humans have not been performed and therefore do not allow for a proper assessment of developmental and reproductive effects in humans (Froines et al., 1998). The carcinogenicity of MTBE has only been tested on animals. Substantial evidence exists proving the carcinogenicity of MTBE in rats and mice by either oral or inhalation routes. It has been concluded from animal tests that MTBE is an animal carcinogen with the potential to cause cancer in humans (Froines et al., 1998).

Most health effects of MTBE occur at extremely high doses. It is therefore unlikely that drinking water standards for MTBE will be set according to health risks. Alternatively, there is considerable public concern over the use of MTBE because it has a low taste and odor threshold. Taste and odor thresholds are not used to set primary drinking water standards, yet they are used to set secondary standards. The taste and odor of MTBE is bitter and turpentine-like and may be linked to reported acute effects associated with MTBE. The California Department of Health Services therefore set a secondary maximum contaminant level (SMCL) for MTBE at 5 ppb (Froines et al.,1998). Therefore, it is most likely that any future standards for MTBE in drinking water will be set on taste and odor thresholds rather than on health effects.

Questionable MTBE Benefits

While the benefits of reformulated gasoline for automotive emissions have been clearly demonstrated, it is not at all clear that the presence of MTBE in reformulated gasoline contributes to improvements in California air quality (Koshland et al., 1998). Reformulated gasoline is designed to reduce exhaust and evaporative emissions of photochemical ozone precursors. Not all reformulated gasoline necessarily contains any oxygenates such as MTBE. The use of reformulated gasoline, with or without oxygenates, reduces vehicle emissions of hydrocarbons, carbon monoxide and other air toxics (Koshland et al., 1998). The use of MTBE in reformulated gasoline is linked to a decrease in carbon monoxide emissions; however, when used in gasoline, MTBE may be emitted as an unburned hydrocarbon during vehicle use. MTBE is currently present in the atmosphere and can react with an OH radical to yield tert-butyl formate (TBF) and formaldehyde. Previous studies conclude that the presence of MTBE in reformulated gasoline is associated with decreased carbon monoxide emissions and increased emissions of isobutene, formaldehyde and unburned MTBE. More current research has concluded that there is no significant air quality benefits associated with the use of MTBE in reformulated gasoline relative to non-oxygenated formulations (Koshland et al., 1998).

Scope of Analysis

Central to this study is the relationship between gasoline formulation and air quality. Improvements in gasoline formulations can affect air quality mainly by reducing the vehicular emissions per mile traveled. Thus, much of the analysis and discussion resulting from the cost benefit analysis focuses on ways of reducing vehicle-mile emissions for California's vehicle fleet.

Of course, air quality would greatly improve if emissions were reduced by any means, not just by reducing emissions per vehicle-mile traveled. Although policymakers may consider a number of these alternate means to meet Clean Air Act requirements, our analysis is limited to gasoline formulation options. A reduction in the number of cars on the road would certainly help improve air quality, as would a reduction in the number and average distance of car trips. These goals may be achieved through a number of policies, including intelligent urban and suburban planning, as well as supporting alternate methods of transportation such as bicycle commuting and public transportation. Population growth will continue to exacerbate California's air quality problems, as a larger population will likely imply a larger auto fleet. Although this study does not address these problems or their solutions, it bears mentioning that issues of California air quality are positioned in a larger context that goes beyond gasoline formulation.

Also noteworthy is the fact that automobiles are not the only source of pollutants to California's air. Other sources include fuel combustion from fixed industrial sources, evaporation of toxic chemicals, and even natural sources such as forest fires, volcanoes, and extraterrestrial objects, e.g. meteorites (Peterson and Young, 1971). Pollution from industrial sources is held in check by the Environmental Protection Agency, and is generally not affected by changes in automotive gasoline formulation, and so these sources of pollution are not considered in this study. Natural sources are considered very minor contributors, and since they are by definition non-anthropogenic, they are beyond the scope of this document.

We focus on automobile gasoline formulation, and consequently limit our analysis to those vehicles which use this fuel, namely gasoline-based autos and trucks. We exclude from our study vehicles using diesel fuel, such as heavy-duty industrial trucks, farm equipment, sea-faring container ships, and rail road locomotives. Additionally, we exclude air transport and gasoline for airplanes that affect air quality. Similarly, we do not consider other fuels known to foul the air when burned, such as coal, wood or other vegetable matter.

While diesel-burning vehicles and their effect on air quality have caused growing public concern, their consideration is simply beyond the scope of a study motivated by MTBE use.

4. Background Information

Atmospheric Chemistry

Understanding air quality management strategies requires knowledge of some of the chemical mechanisms that create and destroy air pollutants. This section provides a brief overview of some of important characteristics of the atmosphere and the chemical processes that occur within it.

The Earth's atmosphere is a mix of gases, dominated by nitrogen (N_2) which comprises 78% of molecules in the atmosphere. Other abundant gases include oxygen (O_2, 21%), argon (Ar, 0.93%), carbon dioxide (CO_2, 0.037%), and water vapor (H_2O, in varying amounts) (Manahan, 1993). The remainder of gases in the atmosphere are present only in very small quantities, and are measured in parts-per-thousand, parts-per-million, or parts-per-billion (ppt, ppm, and ppb, respectively). Even at such extremely small concentrations, trace gases can have a profound effect upon the health of plants and animals (Manahan, 1993). Due to distribution of human activities which contribute to pollution, as well as atmospheric transport mechanisms and reaction rates of various chemical reactions, concentrations of atmospheric pollutants can have a wide spatial variability, as well variability on daily and seasonal cycles (Jacob, 1999).

The National Ambient Air Quality Standards, promulgated under the 1970 federal Clean Air Act (42 U.S.C. 7409 § 109), establish acceptable concentrations for six pollutants: ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), lead, and particulate matter. Several of these pollutants are not problematic for California, which is currently entirely in attainment for nitrogen dioxide, sulfur dioxide, and lead.

While currently only the most populous sections of California are not in attainment for carbon monoxide, much of the state has perpetually mired in non-attainment for ozone. California's automobile fleet, the largest in the nation, is held responsible for contributing to the high levels of these two pollutants (CARB, 1999).

Carbon monoxide is created during the combustion of hydrocarbons in gasoline, and is a highly toxic gas that interferes with the blood's ability to transport oxygen throughout the body. Carbon monoxide can be especially harmful to infants, small children, the elderly and heart and respiratory patients. Typical concentrations of CO in remote parts of the world are 0.05-0.150 ppm, in rural areas are 0.1-0.3 ppm (Jacob, 1999), while the peak measurements in Southern California have topped 14.0 ppm, although levels this high are not common (CARB, 1999). A more typical CO measurement in Burbank can range from 1.0 to 5.0 ppm in one day (as observed by CARB on 12/20/97, the station's 71st highest average measurement that year). Carbon monoxide concentrations are typically highest in California from November to March, when winter climatological patterns inhibit its dispersal. Carbon monoxide's atmospheric lifetime is around two months, considered a relatively short period for atmospheric gasses (Jacob, 1999). CO usually leaves the atmospheric system when it is oxidized by an OH radical.

High concentrations of ozone (O_3) contribute to respiratory problems in humans and animals, and can additionally damage crops and other vegetation (CARB, 1999). Unlike carbon monoxide, which is created during combustion, ozone is created in the atmosphere. An O_2 molecule will react in sunlight with a NO_2 molecule, to produce O_3 and NO in a photochemical reaction. Because O_2 is abundant in the atmosphere, this reaction is limited by the availability of NO_2 and sunlight. NO can be recycled into NO_2 through a number of processes with organic molecules, such as volatile organic compounds (VOCs). Because NO and NO_2 are readily cycled, they are often thought of as a single group, referred to as NO_x, and pronounced "nox" (Jacob, 1999). VOCs are organic compounds, that when in liquid form evaporate readily into the atmosphere, forming reactive organic gases (ROGs). Sources of VOCs include gasoline and other industrial chemicals, as well as from biological sources such as vegetation (National Research Council, 1991).

Although ozone is the toxic pollutant, it is ozone's precursors NO_x and VOCs which are emitted from the vehicle. Therefore, attempts to reduce ambient ozone concentrations often target either NO_x emissions or VOC emissions, or both. Initial efforts to reduce ozone concentrations focused on reducing VOCs, without particular regard for NO_x. For example, Section 185 of the Clean Air Act describes penalties for stationary sources of VOCs in ozone non-attainment areas, but not for sources of NO_x (42 U.S.C. 7409 § 185). More recent studies indicate that, "in the gross average, NO_x and not VOCs is the limiting factor in ozone photochemical production" (National Research Council, 1991).

Additionally, reliable inventories of VOCs from biological sources have become available in the last decade, and these inventories show that, in the United States, VOC emissions from these natural sources are greater than all anthropogenic hydrocarbon emissions (Jacob, 1999). Efforts to curb industrial and vehicular VOC emissions would be met with modest decreases in total VOC concentrations, as biological sources would continue to contribute to these concentrations.

Ozone concentrations are typically highest during the summertime, when more sunlight is available to power ozone-creating chemical reactions. This summer increase of ozone is in contrast to the winter increase of carbon monoxide. Because of these seasonal variations, air quality improvement measures are sometimes only in effect for certain parts of the year.

In spite of this overabundance of ozone in the surface atmosphere, concentrations high in the stratospheric ozone layer have decreased in recent decades, creating what is commonly referred to as "the ozone hole" (Jacob, 1999). Although these two problems involve the same gas, they are otherwise unrelated, as the processes which create and destroy ozone are quite different in the stratosphere than they are at the Earth's surface.

Legal History

As previously mentioned, the federal Clean Air Act (CAA) of 1970 established National Ambient Air Quality Standards (NAAQS) which, to protect public health, set limits on the allowable ambient levels of specific pollutants (42 U.S.C. 7409). The act requires that lawmakers review these standards at least every five years and revise the standards as deemed necessary.

The 1990 amendments to the CAA require the use of oxygenates in areas that exceed the NAAQS for carbon monoxide. Since November 1992, the CAA has required states to implement an oxygenated gasoline program to reduce wintertime CO emissions in non-attainment areas. These state programs require that gasoline sold during winter months in CO non-attainment areas contain oxygen at a minimum level of 2.0% by weight. States may obtain a waiver from the U.S. EPA authorizing a lower minimum oxygen standard.

To address ozone pollution, the CAA 1990 amendments set up a separate, two-phase program requiring year-round sales of Federal Reformulated Gasoline (RFG) in areas in violation of the NAAQS for ozone. Phase I, which began in 1995, established an oxygen requirement and other gasoline specifications (see Table 2) to reduce VOC and toxic air emissions. During Phase II of the Federal RFG program, to start in the year 2000, the U.S. EPA requires additional reductions in NO_x, VOCs and toxic emissions.

In order to meet these CAA requirements, California developed two programs: the Winter Oxygen Program and the California Reformulated Gasoline Program.

In 1991, CARB adopted the Winter Oxygen Program in an effort to reduce carbon monoxide levels. This program established an oxygen requirement for gasoline sold during the winter months. Due to the adverse effect of high levels of oxygenates on NO_x emissions, California requested and received a waiver from the 2.0% oxygen requirement in the CAA. In place of the CAA oxygenate requirement, CARB instituted a 1.8-2.2% winter gasoline oxygenate requirement. This Winter Oxygen Program was adopted statewide, not just in CO non-attainment areas, because about 80% of the gasoline used in California was sold in what were CO non-attainment areas at the time of the program's implementation.

Largely because of the California's Winter Oxygen Program, California has greatly reduced the number of areas in violation of the NAAQS for carbon monoxide. Only the greater Los Angeles area remains in non-attainment with respect to the federal carbon monoxide standard. Once an area comes into attainment with the NAAQS for carbon monoxide, the Winter Oxygen Program is required only to the extent that the program is necessary to maintain attainment status.

CARB adopted regulations for cleaner burning gasoline to jointly address the problems of carbon monoxide and ozone, effective March 1, 1996. This gasoline is known as California Reformulated Gasoline, Phase II (CARFG2). The regulations specify limits on eight properties of gasoline (see Table 2), including a requirement of 1.8-2.0% oxygen by weight. There was no mandate for how to meet this oxygen requirement, so the choice of which oxygenate to use was left up to individual refiners. Overwhelmingly, refiners chose methyl tert-butyl ether (MTBE) because it is inexpensive and readily available from the refining process and blends easily into gasoline. The widespread use of MTBE in California's gasoline continues to the present.

Property	*Conventional*	*Federal RFG*	*CaRFG2 w/ MTBE*
Aromatics, (vol. %)	32.0	max. 25	max. 25.0
Olefins, (vol. %)	9.2	N.S.*	max. 10.0
Benzene, (vol. %)	1.53	max. 1.0	max. 1.0
Oxygen content (%)	0	2.0-2.7	1.8-2.7
Sulfur (ppm by weight)	339	?	max. 40
Reid Vapor Pressure (psi)	8.7	max. 7.2	max. 7.0
T90, ^{o}F	330	N.S.	max. 300
T50, ^{o}F	218	N.S.	max. 210

*N.S. = not specified

Table 2. Specification of Conventional, Federal Reformulated, and California Reformulated Gasolines

Gasoline Formulation

Gasoline is a complex mixture of hundreds of different hydrocarbons. Mixing these hydrocarbons in differing proportions results in varying emissions and engine performance. In 1989, three domestic automakers and 14 oil companies established the Auto/Oil Air Quality Improvement Research Program (AQIRP), a six year study to develop a database on the effects of different fuel compositions and vehicle fleet improvements on emission of pollutants into the atmosphere (AQIRP 1997). Based on the findings of the AQIRP, the 1990 Federal Clean Air Act Amendments (CAAA) set requirements for gasoline composition and performance (42 U.S.C. 7409 § 202).

Aromatics

Aromatics are naturally-occurring hydrocarbons with one or more benzene rings (e.g., benzene, toluene). Aromatics are present in crude oil, and although these compounds are desired from a combustion perspective (they have a high octane), decreasing the aromatic content of gasoline greatly reduces harmful emissions (Manaham, 1993). The results of the

AQIRP study indicated that lowering aromatics can significantly reduce the emissions of hydrocarbons, as well as reducing carbon monoxide emissions. Since aromatics are considered toxic substances (Manaham, 1993), reducing the concentration of aromatics significantly reduces the toxicity of emissions (AQIRP, 1990; AQIRP, 1991a; AQIRP, 1991b; AQIRP, 1991c).

Olefins

Olefins are hydrocarbons, also present in crude oil, containing a double bond. Reducing olefin content causes a modest decrease in hydrocarbon emissions. While reducing olefins has little or no effect on CO or oxides of nitrogen (NO_x) emissions, it does significantly reduce the atmospheric reactivity of the emissions, which results in a decrease in ozone formation (AQIRP, 1990; AQIRP, 1991a; AQIRP, 1991b; AQIRP, 1991c).

Benzene

Benzene is specifically targeted in both the 1990 Federal Clean Air Act and in the State of California regulations, given its known carcinogenicity. Although the AQIRP study did not specifically evaluate the effect of decreasing only benzene on air emissions, the effect is similar to the overall effect of reducing aromatics, and the expected result is a lowering of unburned benzene emissions.

Oxygen Content

The AQIRP study evaluated the addition of several oxygenates, which refers to organic chemicals that contain one or more oxygen atoms in their structure. Crude oil contains only trace amounts of these chemicals, so they must be added to refined gasoline to increase its oxygen content. Some of the oxygenates come from renewable resources, such as ethanol from corn and other agricultural products, while others such as MTBE are synthetically produced from fossil fuels. In addition to improving the combustion process and thus reducing CO in vehicle emissions, some oxygenates increase the octane rating of gasoline, improving vehicle performance.

Octane rating is a measure of a gasoline’s anti-knock properties. “Knocking” describes the loud sound heard from an engine running a low-octane fuel, when fuel ignites spontaneously and prematurely during the piston’s compression stroke. Excessive knocking is hard on the engine and can rapidly induce piston failure. Specifically, octane rating is a measure of the ability of end gasses to spontaneously combust under carefully monitored conditions (Concise Encyclopedia of Chemical Technology, 1985).

Adding MTBE at 15% by volume to gasoline reduces both CO and hydrocarbon emissions, slightly increases NO_x emissions, and has a negligible effect on the emission of benzene, 1,3-butadience, formaldehyde, and acetaldehyde, which are toxic compounds typically present as products of incomplete combustion of gasoline. It also has an insignificant effect on reducing peak ozone concentrations (AQIRP, 1990; AQIRP, 1991a; AQIRP, 1991b; AQIRP, 1991c; AQIRP, 1991d; AQIRP, 1992a; AQIRP, 1995a).

Addition of ethanol to gasoline at approximately 10% by volume produced similar results as MTBE addition in terms of CO, exhaust hydrocarbons, and NO_x. Ethanol addition increased the evaporative emission of hydrocarbons due to the higher volatility of the ethanol/gasoline mixture and also resulted in higher formaldehyde and acetaldehyde emissions than unblended gasoline (AQIRP, 1991d).

Ambient temperatures below 10 ^{0}C result in a decreased effectiveness of either MTBE or ethanol in reducing CO emissions (Most, 1989; Lax, 1994). Increasing altitude also has the effect of reducing the beneficial effect of oxygenates with respect to the reduction of CO (Most, 1989).

Field studies in Denver, Colorado using remote sensing devices evaluated the effect of using gasoline with different oxygen content on CO emissions (Bishop and Stedman, 1989; Bishop and Stedman, 1990). The first study evaluated the use of gasoline with 1.5% oxygen content by weight, which resulted in a reduction of 6± 2.5% in CO emissions during hot, stable operating mode conditions, comparing the emissions during and after the wintertime oxygenated fuel program. The second study during the 1988-89 wintertime program in Denver, when 2.0% oxygen by weight (11% MTBE by volume) was used, found a decrease of 16 ± 3% in CO emissions (Colorado, 1992).

Sulfur

Sulfur is present in various organic and inorganic compounds that are naturally present in fossil fuels. When these compounds are oxidized in the combustion process, sulfur dioxide is formed, which is a precursor to acid rain. It is thus desirable to reduce sulfur from fossil fuels before the combustion process. In addition, sulfur compounds affect the activity of the catalytic converters used in vehicles to reduce CO and hydrocarbon emissions, reducing the life of these control devices (Schmidt, 1998). Reducing the sulfur content of gasoline also reduces hydrocarbons, CO, and NO_x emissions, and it reduces the formation of ozone (AQIRP, 1991e; AQIRP, 1992b; AQIRP, 1995b; Mayotte et al., 1994a; Mayotte et al., 1994b).

Reid Vapor Pressure

Reid Vapor Pressure (RVP) is a measure of the volatility of gasoline and is measured in pounds per square inch (psi). RVP is strongly, positively correlated with temperature. Thus, during hot days there is a high volatilization rate for gasoline, both during fueling operations and from the fuel distribution systems. The AQIRP study showed that decreasing the RVP by 1 psi (prom 9 to 8 psi) decreased fuel evaporative emissions by 4%. CO emissions were also reduced by reducing RVP. Finally, a gasoline with a minimum RVP is necessary to achieve adequate vehicle performance during cold starts (i.e., during the first few minutes of engine operation, before the engine and pollution control equipment heat up).

T50 and T90

The various hydrocarbons that compose a gasoline will evaporate from gasoline at different temperatures. At low temperatures the most volatile components are evaporated, while at high temperatures (e.g. greater than 300 ^{0}F) only the very heavy components remain. One way to characterize a gasoline is its distillation curve, which refers to the various fractions that remain at different temperatures. For example, T50 refers to the temperature at which 50% of the gasoline will have evaporated, and T50 refers to the temperature at which 90% will have evaporated. Reducing T50 or T90 reduces the overall hydrocarbon emissions, but may result in slight increases in overall CO and NO_x emissions. Peak ozone concentrations should also decrease if T50 or T90 are decreased.

5. Methods

Cost Benefit Analysis (CBA) is a method for evaluating proposed projects or policy alternatives by comparing the estimated dollar value of the costs and benefits associated with each alternative (Morgenstern, 1997). Although CBA is a powerful tool for policy makers, it should not be considered the only tool to definitively select the optimal policy, as there are usually other social considerations, aside from balance-sheet calculations, upon which a policy maker should base decisions.

A CBA is useful for demonstrating the contrast between different scenarios: a baseline (typically the status quo) and at least one other scenario under consideration. Our CBA compares three different fuel formulation scenarios against a single baseline. California's history of changing the requirements for its gasoline means that no particular formulation stands out as an obvious or indisputable baseline. We choose for our baseline scenario gasoline sold statewide in California prior to January 1, 1995, hereafter referred to as "conventional gasoline." Against the baseline of conventional gasoline we contrast three other gasoline formulations: (1) California Phase II Reformulated Gasoline (CaRFG2) with MTBE; (2) CaRFG2 with ethanol; and (3) Non-oxygenated CaRFG2. The CaRFG2-ethanol blend meets the CaRFG2 standards by adding ethanol; the specifics of ethanol blends under consideration are discussed in Section 6. The non-oxygenated CaRFG2 blend uses toluene to meet these standards, and was selected as a feasible alternative based on conversations with refinery representatives.

The scenarios we consider assume that the specified fuel is used exclusively throughout California, year around. In reality, formulations vary somewhat by producer, by region, and by season. Acknowledging the actual differences in the fuel formulations, we consider these slightly simplified scenarios to accurately represent the results of the policy alternatives under consideration.

Conducting a CBA is similar to preparing a balance sheet. First, the dollar values of the costs and benefits are categorically determined; these values are then summarized and compared. The sum of the benefits minus the sum of the costs yields the net benefits. A higher net benefit indicates a better alternative, from an economic perspective (Boardman et al., 1996). We decompose the costs and benefits of each alternative into the following cost and benefit categories (Keller et al., 1998a):

- Human Health
  - Air Quality Benefits
  - Air Quality Costs
  - Water Treatment or Alternative Water Supply Costs
- Direct Costs
  - Fuel Price Increase
  - Mileage Decrease
- Other Costs to the Economy
  - Monitoring Costs
  - Recreational Costs
  - Ecosystem Damages

Determining a dollar value for a particular cost and benefit category for a scenario requires estimates of two important quantities: the magnitude of the effect (in terms of a number of instances), and the cost of each instance. For example, determining the direct at-the-pump cost for all of California would require estimating both the price per gallon and the number of gallons sold per year in California at that price. Determining the benefit of a reduction in chronic bronchitis requires an estimation of the reduction of total cases of the disease, as well as a dollar value associated with the avoidance of a single case. Both of these examples require estimations, some of which may be made with more certainty than others. In areas where uncertainty is high, we use a range of values, representing the likely low and high bounds for the actual value.

Details of the valuation calculations made for each cost and benefit are provided in Section 6 (Results) for each fuel alternative. Table 3 presents a brief summary of the valuation techniques used for different cost and benefit categories. The references refer to general descriptions of the valuation methods, except for Keller et al. (1998a), Rodriguez (1997), and Tikkanen (1998), which refer to valuation studies specifically applied to MTBE and fuel alternatives in California.

To determine the value of morbidity effects from polluted air and water, we use the cost of illness and avoidance expenditures approach described by Abdalla et al. (1992). For the health costs of mortality effects associated with direct contact with contaminated water or air, we use the value of a statistical life as determined by Fisher et al. (1989), adjusted to account for inflation over time.

Category	**Valuation Method**	**Description of Method, Reference**
Human health effects from water and air impacts	Cost of Illness	Value of morbidity using medical costs & wages, Berger et al., 1987
	Statistical Life Value	Mortality, Fisher et al., 1989
	Avoidance Expenditures	Value using costs of goods to avoid risk, Abdalla et al., 1992
Water Treatment	Direct Price	Engineering estimates and market prices, Keller et al., 1998b
Alternative Water Supply	Direct Price	Market prices, Rodriguez, 1997
Fuel price increase	Direct Price	Spot price components and market prices, Rowe et al., 1990; Evans, 1997
Fuel efficiency	Direct Price	Engineering estimates and market prices, Krupnick and Walls, 1992
Monitoring costs	Direct Price	Engineering estimates and market prices, Tikkanen, 1998
Recreational costs	Travel Cost	Expenditures for engaging in recreation, Bockstael et al., 1991
Ecosystem damages	Factor Income	Income from output produced by ecosystem, Bell, 1989
	Restoration Cost	Engineering estimates and market, Shabman and Batie, 1987

Table 3. Valuation methods.

Our estimates of water treatment costs are based upon observed market prices and engineering estimates. Either as a stop-gap measure or in lieu of treating contaminated water, consumers may instead choose to switch their water source from polluted groundwater to an alternate source. In these cases, we use a representative market price of potable water from surface water sources.

We have relied on the comparison of market prices among fuel formulations, or components of fuel formulations, to measure the direct cost increase paid by consumers, due to the use or hypothetical use of a particular oxygenate. In so doing, we assume that any increases in variable costs faced by refiners are passed on to the consumer in the form of higher at-the-pump prices. Costs associated with the loss of mileage resulting from the use of a given oxygenate are based upon published estimates of the per gallon fuel efficiency of fuel blended with that oxygenate, or implicitly from measures of the energy content of the oxygenate. Here we assume that the demand for total miles traveled is invariant to the efficiency of the fuel used.

We use observed market prices to determine the monitoring costs associated with measuring the extent of contamination in the ambient air, as well as in surface and ground water sources. To value the value of recreational activities that may be curtailed (such as boating and riding jet skis) to protect surface water reservoirs, we use the travel cost method.

Our analysis considers the annualized costs of using various fuels for a single year, and does not attempt to describe outcomes in future years, nor estimate the cumulative costs and benefits over time. In many respects, our fuel usage scenarios are unlike large construction projects, where the largest costs must be borne up front while the benefits are accrued for years into the future. Such projects would require a multi-year, dynamic study that employed a discount rate to account for the change in the value of money over time. We do recognize fuel formulations and other technologies may be dynamic in nature and might ideally require a dynamic analysis over the long term. However, we feel the more simple, static analysis is the most appropriate for California's policy makers, given the uncertainty associated with selecting a discount rate and estimating future costs and benefits.

The valuation of environmental and health impacts of each alternative leads to necessarily uncertain results, as several of the input factors for these calculations are not measured or are not known with great certainty. For example, the precise marginal effects of MTBE on a host of diseases is not known, as the necessary epidemiological studies have not been conducted. Additionally, the effects on human health of reducing ambient air pollution levels below federal air quality standards may be estimated only in vague and uncertain terms.

Most environmental goods are not traded in markets, and so do not have explicit prices. To estimate accurate monetary equivalent values for these goods, we use a number of indirect approaches. The details of these methods are explained in the sections of this document where the derived values are used.

Note that there are some costs and benefits that may not be included in our study because they are extremely difficult to value quantitatively. For example, we limit our analysis of environmental damage to commercially important species, and do not attempt to value damage that might inflict a cost upon plants or animals that do not contribute to the economy. Changes in air quality that may result in mild annoyance or decreased visibility are similarly difficult to evaluate, and we do not attempt to do so. Rather, our study considers only the changes in air quality that affect the occurrence of diseases and their symptoms.

6. Cost Benefit Analysis Results

We have determined that using CaRFG2 with MTBE is the most costly of the alternatives, while using nonoxygenated CaRFG2 is the most beneficial. These conclusions, as well as the estimated values for each cost benefit category for the three alternatives, are summarized in Table 4. These values are relative to the baseline of conventional gasoline.

	CaRFG2-MTBE	**CaRFG2-Ethanol**	**Non-oxy CaRFG2**
Air Quality Benefits	**$2** to **$66**	**$2** to **$66**	**$2** to **$66**
Health Costs			
air quality damages	($27) to $0	($200) to ($3)	N.S.
water treatment	($1,480) to ($340)	N.S.	($10) to ($1)
alternate water supplies	($30) to ($1)	N.S.	N.S.
Direct Costs			
fuel price increase	($970) to ($280)	($610) to ($220)	($280) to $280
mileage reduction	($400) to ($310)	($580) to ($290)	$150 to $230
Other Costs			
water monitoring costs	($4) to ($2)	N.S.	N.S.
recreational costs	($340) to ($230)	N.S.	N.S.
ecosystem damages	N.S.	N.S.	N.S.
Costs Subtotal	**($3,251)** to **($1,163)**	**($1,390)** to **($513)**	**($140)** to **$509**
Net Benefit (or Cost)	**($3,249)** to **($1,097)**	**($1,388)** to **($447)**	**($138)** to **$575**

All costs and benefits are expressed in millions of dollars per year. "N.S." stands for "Not significant"

Table 4. Annualized Cost Benefit Analysis of Fuel Alternatives

A few of the details in the above summary are worth noting. First, the air quality benefits of the three alternates are effectively indistinguishable, according to Koshland et al. (1998). Since the government's requirement to add an oxygenate to gasoline was ostensibly implemented to improve air quality, the apparently minor influence that oxygenation has had in improving air quality should raise questions regarding the necessity of continuing to require oxygenates.

Also notable is the fact that the largest costs associated with using MTBE are in water treatment costs, fuel price increases, and mileage reductions. Additionally, significant recreational costs count only against the MTBE usage scenario, and not towards the others, given that MTBE use is the only scenario necessitating boating restrictions due to its deleterious effects on water quality.

Only considering direct costs, the use of either of the oxygenates (MTBE or Ethanol) would incur roughly the same costs, while the use of non-oxygenated CaRFG2 would be considerably cheaper. The similarity of direct prices for oxygenates explains why refiners continue to produce gasoline with MTBE, even though it is the least cost effective alternative for the state. Legal requirements preclude refiners from using non-oxygenated CaRFG2, and because an ethanol blend is not markedly cheaper for them, most refiners produce gasoline with MTBE to meet the CaRFG requirements. Although there are some significant costs associated with using MTBE, such as the costs related to water treatment, mileage reduction, and recreation, these costs are not borne by the refiners. A conversion to ethanol or a non-oxygenated fuel might require refiners to bear significant fixed costs, and could result in serious price shocks.

Figure 2 illustrates the numbers from Table 4. To show the range of values, both the highest estimations and the lowest estimations are shown for each scenario.

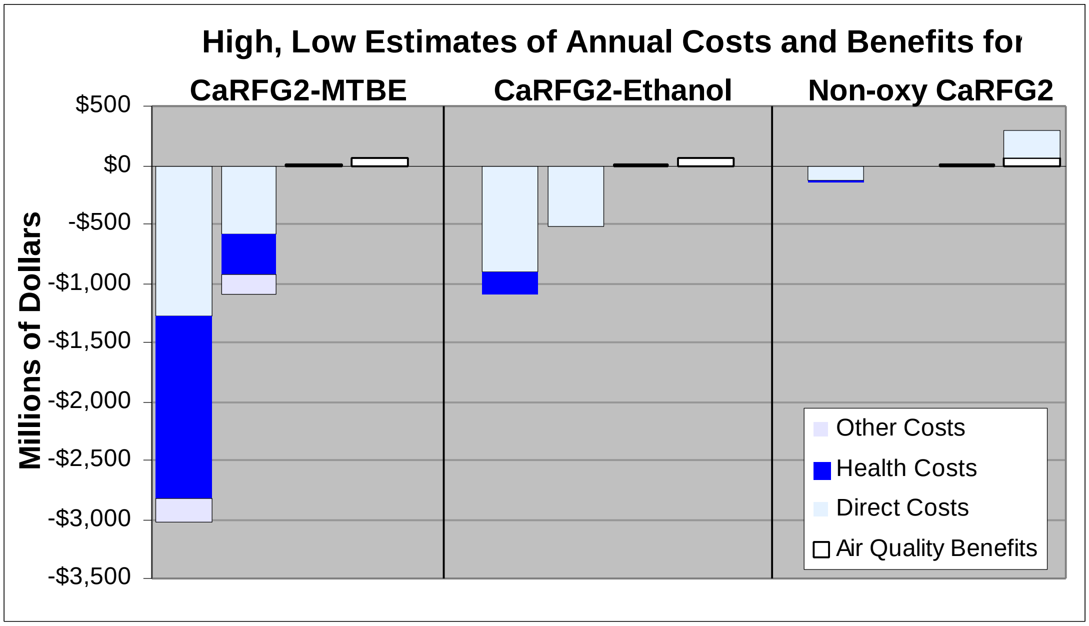

Figure 2. For each alternative, the maximum and minimum costs are shown on the left, while the minimum and maximum benefits are shown on the right.

In a pessimistic analysis, considering only the high-range cost estimate costs and low-range benefit estimate, the costs dominate while the benefits are comparatively negligible. In this case, the difference between the costs and the benefits is essentially the value of the costs. However, in an optimistic analysis, considering the lesser cost estimates and the greater benefit estimates, the oxygenated fuel scenarios show a net cost, while the non-oxygenated scenario shows a net benefit, as illustrated in Figure 3.

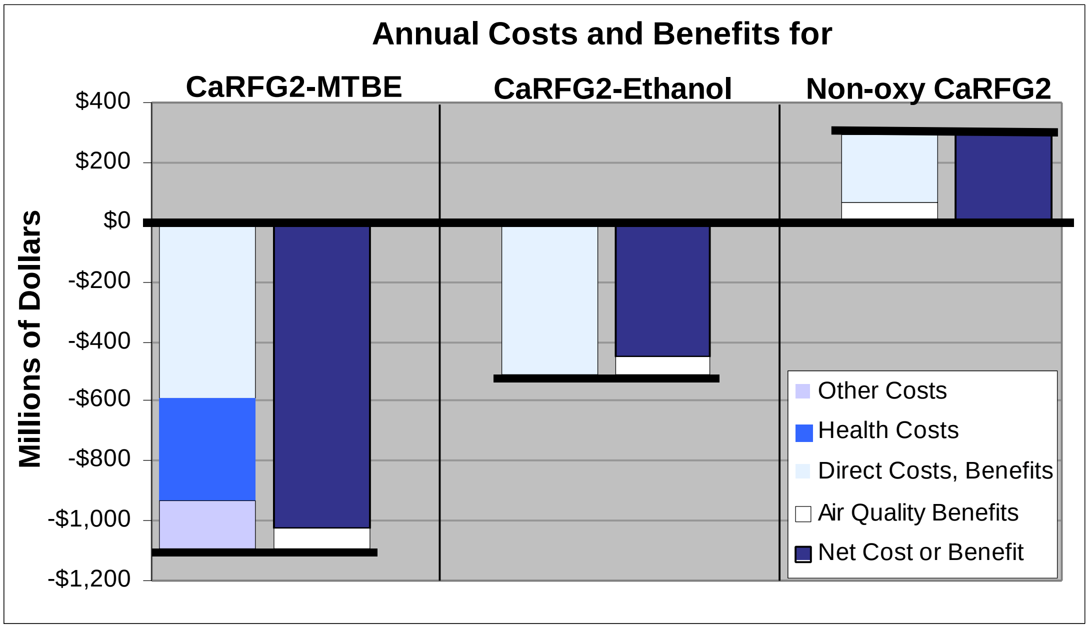

Figure 3. Summary of annualized cost benefit analysis of fuel alternatives, using low estimates for costs and high estimates for benefits. Dark bars represent the net cost or benefit for each alternative (i.e. the difference between the total costs and total benefits)

These results indicate that the continued statewide use of oxygenated gasoline is not a cost effective strategy. The following sub-sections present the assumptions used in our valuations, as well as a discussion of each cost or benefit category.

Air Quality Benefits of Reformulated Gasoline

Statewide sales of any gasoline meeting CARFG2 specifications (with MTBE, ethanol, or non-oxygenated) is expected to decrease the atmospheric concentrations of ozone, carbon monoxide, and benzene (Koshland et al., 1988). Of these harmful compounds, benzene has the most detrimental impact on human health (ATSDR, 1991; IARC, 1985). Benzene is a known human carcinogen which can increase the incidence of leukemia in exposed populations. To estimate the economic benefit of a reduction in ambient levels of benzene, we multiply benzene's cancer potency by the estimated change in benzene concentration. This product is the estimated decrease in cancer risk per million people. Multiplying this result by the population most likely exposed to benzene, we obtain the estimated statewide decrease in cancer. We used an annualized value of a statistical life to translate a decrease in cancer into a monetary value (see Table 5).

	Benzene[1]	**Formaldehyde**[2]	**Acetaldehyde**[3]
Cancer Risk Factor $(ug/m^3)^{-1}$	7.50×10^{-6} to 5.30×10^{-5}	2.50×10^{-7} to 3.30×10^{-5}	9.70×10^{-7} to 2.70×10^{-5}
Cancer Risk Factor ppb^{-1}	2.72×10^{-5} to 1.92×10^{-4}	3.08×10^{-7} to 4.06×10^{-5}	1.75×10^{-6} to 4.86×10^{-5}
Estimated change in concentration	-0.06 to -0.16 ppb	0 to 0.32 ppb	1 to 2 ppb
Estimated exposed population	22 million to 29 million	22 million to 29 million	22 million to 29 million
Statewide change in cancer cases	(33) to (920)	0 to 380	38 to 2800
Cost per Cancer Case	$5,000,000	$5,000,000	$5,000,000
Total cost of potential cancer cases	($165 to $4,600 million)	$0 to $1,900 million	$190 to $14,000 million
Annualized cost of Cancer for average 70 year life	($2.35) to ($65.5) million	$0 to $27 million	$2.7 to $200 million

[1] For any CaRFG2 formulation. [2] Due to MTBE [3] Due to Ethanol

Table 5. Economic value of changes in atmospheric concentrations (values in 1998 dollars)

The range in cancer potency has been established by a scientific review panel (CAL-EPA, 1997). Cancer potency expresses the per capita risk of contracting cancer based upon ambient concentrations of the pollutant. These values are given in terms of per capita risk per ug/m^3 of pollutant; we convert the units of measurement to per capita risk per parts per billion (ppb).

The change in ambient concentrations attributable to the introduction of CaRFG2 is complicated by the difficulty in separating the effects due to gasoline formulation from effects due to other causes, such as changes in the automobile fleet, gas consumption, and weather patterns. For benzene, we analyzed the 1990 to 1995 trend in change in ambient concentration of benzene, and compared this to the change from 1995 to 1996, the year CaRFG2 was introduced. Although ambient concentrations may vary widely depending upon location and time of year, to simplify this analysis we assume that the annual average is uniformly distributed for the regions measured. To control for the effect of changes in gasoline consumption over the different periods, we divide the change in benzene concentration by the volume of gasoline sold. Annual average ambient benzene concentration figures are from CARB monitoring data; annual gasoline sales figures are from the California Energy Commission, (CEC, 1998a). The 1990-95 period indicates a 14% decrease each year in average benzene concentration, while 1995-96 had a 34% decrease, as is shown in Figure 1. The dotted line represents the 5-year trend (1990-1995). There is some variability in the year-to-year decrease. The departure from the trend in 1995-96 is due in part to the introduction of CaRFG2, but is also likely due in part to the vehicle buyback program to remove high-emitters, which was ramped up over roughly the same period (early 1996). We estimate that CaRFG2 is responsible for somewhere between 25% to 75% of the improvement in air quality, or a 0.06 to 0.22 ppb decrease in ambient benzene concentrations.

Rather than assuming that all California residents are exposed to equal levels of these pollutants, it is more reasonable to assume that only those residents living in areas suffering from poor air quality face increased cancer risk from these pollutants. To estimate the minimum number of people who would be exposed to these levels of pollution, we consider the current populations in the San Francisco Bay Area Air District and South Coast Air District. For the upper bound estimate, we also include those living in the San Diego, Sacramento, and San Joaquin Valley Air Districts.

Multiplying the risk factor by the change in ambient concentration yields the per capita change in risk due to the introduction of CaRFG2; multiplying this number by the estimated exposed population yields the change in number of cancer cases expected (over the lifetime of the population) due to the change in gasoline. We calculate a range for the air quality benefits of $2 million to $66 million using a statistical value of life of $5 million multiplied by the potential reduction in cancer cases. The $5 million is based on an estimate by Fisher et al. (1989), updated to account for inflation. Since our study measures annualized costs and benefits (rather than total costs and benefits), the benefit is divided by an average lifetime used to calculate the cancer potency (70 years) to yield the annual dollar value of the benefit of reducing benzene concentrations.

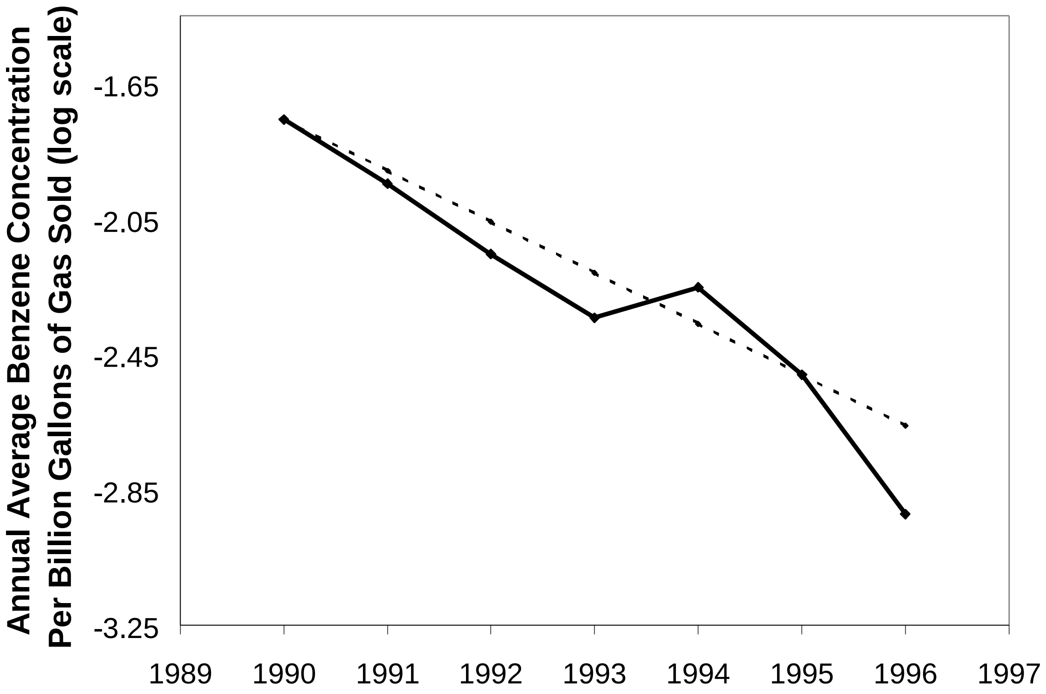

Figure 4. Annual average benzene concentration in California (Per billion gallons of gasoline sold, log scale)

1,3-butadiene is a carcinogen in laboratory animals and is classified as a B2 carcinogen (probable human carcinogen) (U.S. EPA, 1993a; Calabrese and Kenyon, 1991; IARC, 1985). An evaluation of the downward trend in 1,3 butadiene concentrations indicates that there is no statistically significant change in trend in 1995-96 compared to the 1990-95 annual average decrease. Assuming that the decrease in emissions translates directly into a decrease in atmospheric concentrations is not justified by the available air quality monitoring data.

Carbon monoxide increases the levels of COHb in the bloodstream. COHb saturation in the blood stream strains the heart, impairing coordination and ability to judge time, slowing down reaction time and impairing mental abilities (Aronow and Isbell, 1973). These effects typically are observed at levels above 30 ppm. Coronary artery disease is of great concern due to the fact that levels of 2.0 % CO have caused adverse effects to these individuals (Allred et al., 1991). Healthy individuals are also affected, but only at higher levels of exposure. Angina pectoris is also aggravated from increased CO levels (Lambert et al., 1991). Linkage of cardiovascular disease to CO is evident from increased hospital visits during increased air pollution. Recent research reports that in seven cities, ambient CO levels were positively linked to hospital admissions for congestive heart failure in the elderly (Morris et al., 1995; Schwartz and Morris, 1995).

However, levels of carbon monoxide prior to the introduction of CaRFG2 were less than 15 ppm in practically all air basins in California. At present, there is only one non-attainment area for carbon monoxide, namely the South Coast. This reflects the success of many different CARB policies over the last decade. Since the air quality standards are set to be protective of human health even for sensitive individuals, the benefits of pollutant concentration reductions very near or even below the air quality standard are difficult to determine quantitatively. Toxicological or epidemiological evidence is insufficient at these levels to warrant extrapolating the benefits of further reductions in carbon monoxide concentrations.

Exposure to ozone for 6 to 7 hours, even at relatively low concentrations, significantly reduces lung function and induces respiratory inflammation in normal, healthy people during periods of moderate exercise. It can be accompanied by symptoms such as chest pain, coughing, nausea, and pulmonary congestion (Kleinman et al., 1991). Recent studies provide evidence of an association between elevated ozone levels and increases in hospital admissions for respiratory problems in several U.S. cities. Sensitive individuals are affected at levels above 0.15 ppm (Breslin, 1995). California has set a 1-hour standard of 0.09 ppm, while the Federal standard is 0.12 ppm for 1-hour. As in the case of carbon monoxide, determining the health benefits of decreases in ozone concentrations at levels near the standard is difficult to quantify given the lack of toxicological or epidemiological data at low concentrations. Clearly, achieving the standard has an economic benefit, but extrapolating from the available data is unwarranted.

Air quality in California continues to improve, due largely to improvements in motor vehicle technology and the retirement of older vehicles which tend to pollute more. As air quality improves, the impact of reformulated gasoline such as CaRFG2 on ambient air quality will decrease, when measured in absolute terms. For example, by the year 2000, the decrease in benzene concentrations is estimated to be only 0.03 to 0.08 ppb; the reduction in cancer risk is thus smaller than at the introduction of CaRFG2. We therefore expect the human health benefits of CaRFG2 to decrease over the next few years.

Air Quality Costs

Reformulated Gasoline with MTBE

The exposure assessment by Froines et al. (1998) for urban air environments indicates that most individuals will be exposed to levels of MTBE, which are below the one-in-a-million cancer risk. More significantly is the production of formaldehyde as a combustion byproduct of MTBE. Formaldehyde is a probable carcinogen in humans based on sufficient animal studies and limited human studies (Group 2A) (U.S. EPA, 1993c; U.S. EPA, 1988; IARC, 1985). CARB monitoring data on formaldehyde is only available from 1996 onward (Redgrave, 1998). An analysis of the trends in formaldehyde concentrations at more than 20 monitoring locations in California indicates low to high variability (most noticeable a high variability in the LA region) but no clear increasing trend from January 1996 to December 1997, which would just span the wide-scale introduction of CaRFG2 in June, 1996. Based on on-road studies and dynamometer tests (Koshland et al., 1998), formaldehyde concentrations could increase by 10-12%. We estimate the increase to be from 0 to 0.2 ppb based on the average levels of formaldehyde in California. This translates into a total cost of up to $27 million.

Tertiary-butyl alcohol and isobutene are also MTBE combustion byproducts of concern. Low dose chronic toxicity data and proper exposure assessments are not available for either of these compounds. Therefore it is not possible to analyze their effect on morbidity or cancer risk.

Reformulated Gasoline with Ethanol

The use of ethanol as an oxygenate, substituting MTBE, could result in significant increases in acetaldehyde emissions, with a corresponding increase in atmospheric concentrations. U.S. EPA has designated acetaldehyde as a B2 probable human carcinogen (U.S. EPA, 1993b; U.S. EPA, 1987; CARB, 1993; IARC, 1985). RFG with ethanol has been introduced into several regional markets in the US. Concentrations of acetaldehyde have increased in some regions, but differences in air basins and annual variations in meteorology result in variable effects. A more detailed study using numerical modeling may more accurately predict the effect of introducing CaRFG2 with ethanol in California's urban environments. We estimate the increase based on a well documented study of a 1-2 ppb increase in acetaldehyde concentrations after using ethanol/gasoline mixtures in New Mexico (Gaffney et al., 1997). The total cost may be from $3 to $200 million dollars.

Peroxyacetyl nitrate (PAN) is also an ethanol combustion byproduct. PAN is a significant lachrymator. A concentration of 4.95 mg/m^3 PAN in air causes significant eye irritation over 20 minutes of exposure. Eye irritation was also evident during a 2 hour exposure to 0.64 mg/m^3 PAN (Vyskocil et al., 1998). Several studies have been conducted on the effects of PAN on the respiratory system in humans while exercising. Two reported minor but significant changes in respiratory functions, while five concluded that there were no effects. A concentration of 0.64 mg/m^3 PAN was the lowest dose tested (Vyskocil et al., 1998). PAN has also been shown to affect plant tissues (Sun and Huang, 1995; Halek, 1995). PAN is present in most urban air basins as a secondary by-product of the combustion of fossil fuels, which produce acetaldehyde and NO directly. For a majority of urban environments using reformulated gasoline with MTBE, PAN concentrations range from 1-10 ppb (Grosjean et al., 1996). The highest PAN concentrations in Los Angeles County have been measured in Claremont at 9.9 ppb and in Los Angeles at 6.9 ppb (Grosjean et al., 1996). These levels are significantly below the levels that cause adverse effects. We do not included PAN in our economic analysis due to incomplete toxicological information. Low dose chronic toxicity data and a complete exposure assessment are necessary to evaluate the possible health effects of PAN.

Non-Oxygenated CaRFG2

To produce non-oxygenated CaRFG2, the most likely replacement of MTBE, is toluene (according to industry representatives, e.g., from Chevron). One immediate concern is the potential increase in toluene concentrations. Toluene can be neurotoxic at high concentrations (ATDSR, 1992). According to the U.S. EPA, toluene has a Reference Concentration (RfC) in air of 0.4 mg/m^3 or 400 ug/m^3 (U.S. EPA, 1993d). In California, the mean concentration in air is 8.5 ug/m^3. This concentration could increase significantly and still not be close to the RfC, where adverse effects would be measurable. Addition of toluene to CaRFG2 apparently would not result in significant health risk or costs. Additional low dose chronic toxicity studies must be performed in order to conduct a full assessment.

Direct costs of fuel price increase and decline in vehicle mileage

Direct Costs of using MTBE in CaRFG2

Since MTBE is the primary oxygenate used by refiners to meet CaRFG2 requirements in terms of oxygen content, the additional cost associated with using MTBE, due to its higher price relative to conventional gasoline, has been passed on to California consumers. An exact calculation of this cost is not entirely straightforward for a number of reasons:

1. While the use of CaRFG2 is a statewide requirement, several areas of the state, by virtue of their status as federal ozone non-attainment areas, are subject to federal regulations regarding reformulated gasoline composition. Two of these air basins, Los Angeles and San Diego were required to use federal RFG starting January 1, 1995 and a third area, Sacramento, entered the federal RFG program on June 1, 1996. Consequently the geography and history of reformulated gas use in California is not simple, which complicates an analysis of changes in retail and wholesale prices.

2. Beginning in 1992, California initiated a winter oxygenates program, following federal requirements. The winter time oxygenation requirement varied slightly from basin to basin in terms of designating in which months the requirements applied. This again complicates the comparison between prices.

3. Producers have some flexibility in terms of how the requirement is actually met. Most producers adhere to the flat limits for oxygen content, which are 1.8-2.2% in both

> winter and summer. However, CaRFG2 regulations allow alternative formulations with different specifications for relevant parameters if the gasoline generates engine exhaust emissions equivalent to or lower than those generated by fuel which meets the flat limit specifications, based on the predictive model. Producers are free to decrease the oxygenate content for such alternative formulations to zero. Therefore, the exact oxygenate content of a gasoline may vary from refiner to refiner, region to region, and month to month, distorting the price analysis.

Despite these complexities which make the timing of MTBE use and market penetration difficult to pin down, there are several ways to estimate the direct cost of MTBE-oxygenated fuel to the State of California. The first is to examine the difference in retail prices between conventional and oxygenated gasoline either temporally or geographically in such a way that this difference might be attributable to the true cost of oxygenated gasoline above and beyond conventional gasoline. While this approach does provide the most direct measure of cost, it does encounter some obvious difficulties. Retail prices are subject to large variations and respond to a multitude of factors. Consequently it is difficult to attribute differences in prices at the pump either through time or from area to area simply to differences in gasoline formulation. Furthermore this method does not allow for the estimation of the costs of hypothetical gasoline formulations or distribution scenarios which do not have existing markets.

A second method involves evaluating the difference between wholesale prices for conventional gasoline and RFG. Again, this approach is complicated by regional and temporal variations in prices, but should be less subject to local pricing decisions that affect retail prices.

A third method of valuation is to produce a simple model of the wholesale cost of a specific formulation based upon the price of its constituent components. This approach allows for consistent evaluation of direct price increase relative to conventional gas between MTBE and the hypothesized statewide use of ethanol as an oxygenate. However while this method avoids some of the complex volatility of retail price comparisons it clearly does not measure what it is we are actually after, the cost to consumers, as directly as retail comparisons do.

Consequently we have relied on analyses and studies which employ all three approaches in order to establish a range of costs.

Retail Prices of RFG

Between November of 1996 and May of 1998, the national average retail price of conventional gasoline compared to the national average price of RFG was lower by about 4 cents per gallon. This difference was as large as 8 cents in November of 1997. However, in the same month in 1996 the price of conventional gasoline actually exceeded the price of RFG. This is an example of the flaws inherent in a retail price comparison approach for determining the additional cost of using oxygenated fuel. The observed premium for reformulated gasoline, if in fact a premium is observed, depends on a number of factors including the price of oxygenate relative to the price of gasoline. Table 6 presents the available data.

	Nov 96	**Feb 97**	**May 97**	**Nov 97**	**Feb 98**	**May 98**	**1996-98 Average**
National Price Data							
Conventional Areas	87.3	85.4	82.9	78.0	67.1	68.7	
RFG Areas[2]	86.6	88.4	86.3	85.9	72.2	73.6	
RFG minus Conventional	-0.7	3.0	3.4	7.9	5.1	4.9	3.9
Western U.S. Price Data							
Conventional Areas	96.4	95.9	96.7	97.7	81.7	80.9	
RFG Areas[2]	77.7	86.9	91.2	93.2	75.3	79.2	
RFG minus Conventional	-18.7	-9.0	-5.5	-4.5	-6.4	-1.7	-7.6
West minus HI and AK							
Conventional Areas	92	91.8	94.1	96.2	78.0	78.5	
RFG Areas[2]	77.7	86.9	91.2	93.2	75.3	79.2	
RFG minus Conventional	-14.3	-4.9	-2.9	-3	-2.7	0.7	-4.5

[1] Source: U.S. Department of Energy, 1998

[2] RFG areas are those in which 2.0 percent oxygen is required

Table 6. Average Retail Prices of Conventional Gasoline and RFG[1]
(data in cents per gallon)

Furthermore there may be geographical peculiarities in the magnitude of this premium. In the large multi-state region, PADD V (one of five Petroleum Administration for Defense districts), that includes Alaska, Hawaii, Nevada, Arizona, California, Oregon and Washington, the retail price of RFG is routinely cheaper than that of conventional gas. Many of these states use a larger fraction of RFG than conventional gasoline, which means that the lower volume production of conventional gasoline, and thus the higher distribution costs, may actually reverse the retail prices. Consequently, examining retail prices in the western region of the United States is not particularly conclusive. Based on national retail price data however, it appears that reformulated gasoline costs average 4 cents per gallon more than conventional gasoline and ranges from 0 to 8 cents per gallon.

Wholesale Prices of RFG with MTBE

Wholesale reformulated and conventional gasoline prices (net of taxes) were analyzed, for the nation, the PADD V region and California. There is little difference between California and the nation as a whole (Table 7). The premium paid in 1996 for reformulated gasoline is between 6.8 and 7.3 cents per gallon. The premium is considerably less in the Western region as a whole given the expense of conventional gasoline in western states other than California.

Wholesale Prices	U.S.	PADD V	PADD V without HI & AK	California
Conventional	69.4	78.8	77.6	72.2
Reformulated	76.7	79.0	79.0	79.0
RFG minus conventional	7.3	0.2	1.4	6.8

Source: U.S. Department of Energy, 1997

Table 7. Average 1996 wholesale prices of conventional gasoline & RFG (data in cents per gallon)

Formulation-based Valuation of RFG Cost

It is also possible to estimate the price difference between reformulated gasoline and conventional gasoline by taking an average of the wholesale price of MTBE and gasoline and calculating the price of a typical 11% MTBE/gasoline blend by volume, which yields a 2%

oxygen content. We calculated a three year-average (1995-1997) for the price of MTBE of 83.7 cents/gallon based on Gulf Coast Spot/Barge prices as reported in Platt's Petrochemical Service *Motor Fuels Data* (1999). Similarly, we calculated a three-year national average price for wholesale gasoline (unoxygenated) of 72 cents per gallon using Platt's Petrochemical Service *Motor Fuels Data* (1999). Using these values for an 11% mixture we obtain a hypothetical wholesale price for reformulated gasoline of 73.3 cents per gallon. This suggests a premium of one to two cents per gallon for wholesale reformulated gasoline. This calculation is of course sensitive to fluctuations in the price of MTBE, where a 10 cents per gallon increase in the price of MTBE translates to 1.1 cent-per-gallon increase in RFG production cost. Furthermore, contract and spot prices tend to differ widely. Deciding which of these two constitutes the most appropriate measure depends on the particular market circumstances at any given time.

Other Studies of RFG Price Increases

There is not consistent agreement between studies that have attempted to analyze the cost per gallon for producing RFG, either on an absolute basis or relative to producing conventional gasoline. There are a number of reasons for the variation in estimates. One is that the cost impact of RFG production increases with the percent of RFG produced (Zyren and Riner, 1996). Also, cost impacts depend on the types of crude oil the refinery can process and the types of process facilities in the refinery. Another reason for the large variation in cost estimates is that the basis against which RFG production costs are compared is not always the same. Differences can also result from the refinery modeling methodology used as well as the input data used for process yields and qualities as well as operating and investment costs. Studies to date include:

1) The 1993 National Petroleum Council study estimated a range of 3.0 to 7.0 cents per gallon for the increased cost to produce deliver and use RFG. (NPC, 1993).

2) The US Department of Energy's Energy Information Administration combined market estimation techniques with production cost information from other sources to show a 3.9 cents-per-gallon premium in the summer and a 3.5 cents-per-gallon premium in the winter. (Lidderdale, 1995).

3) The Energy Information Administration’s analysis of the reformulated gasoline market in 1995 estimated the average cost to produce RFG in areas such as California where RFG demand and percentage of refinery output is high to be 5.7 to 6.1 cents on average. (Zyren and Riner, 1995).

4) The California Air Resources Board’s 1991 study based on information provided by oil refining companies estimated that CaRFG2-MTBE would cost 5 to 15 cents more per gallon than conventional gasoline (CARB, 1991).

5) A study prepared for the Oxygenated Fuels Association by Lundberg Survey Incorporated (1997) compares the prices of conventional and reformulated gasoline in cities across the nation. This report estimates that national implementation of RFG Phase I (not as stringently regulated, therefore not as expensive as CaRFG2 with MTBE) led to a price increase of 2.89 cents per gallon.

6) The Fuels Resources Office of the California Energy Commission reports “Historical Yearly California Gasoline Prices Per Gallon 1970-1998,” (CEC, 1998a). This study based on 1995 dollars estimates a price increase of 5 cents from 1994 (statewide use of conventional gasoline) to 1996 (statewide use of CaRFG2 with MTBE starting June 1) and a price increase of 14 cents from 1994 to 1997 (the first full year of statewide use of CaRFG2 with MTBE).

Taking all of the different approaches into account, it seems reasonable to assume a premium for RFG of approximately 2 to 7 cents per gallon. The annual extra cost to California of using MTBE to meet CaRFG2 requirements, assuming an annual consumption of 13.5 billion gallons (Board of Equalization, 1998), is $278 to $973 million.

MTBE Effects on Mileage

Vehicle mileage decreases when oxygenates are added to conventional gasoline, due to a reduction in the energy content of the fuel. Based on published studies of energy content and field tests of observed miles per gallon compiled, we estimate a 1.6-2.1% decrease in vehicle mileage due to the addition of MTBE (NSTC, 1997). In order to estimate the monetary value of this increased demand, we use a four-year average (1995-98) statewide retail price per gallon of $1.38, in 1998 dollars (CEC, 1998a). The cost to California of the reduced vehicle mileage of CaRFG2-MTBE can be computed to range from $310 to $400 million.

Studies which examined the cost of increased maintenance and decreased engine performance due to the use of RFG were reviewed by Monzon and Kennedy (1998). Findings from these sources indicate that there is no significant increase (or decrease) in maintenance costs or changes in engine performance associated with the use of RFG. It should be noted that MTBE is used in racing motor vehicles at much higher volume fractions than in RFG, due to its higher octane rating, and therefore would not be expected to cause any unforeseen changes in automobile performance. We do not estimate any additional cost to California consumers due to maintenance or engine performance.

MTBE Octane Enhancement Considerations

MTBE has a high octane rating and consequently raises the octane value of the fuel with which it is mixed. Thus, MTBE has value as an octane enhancer, allowing refiners to blend it with cheaper lower grade gasoline. Estimating the potential savings from this practice is difficult. Not all refiners are in a position to take advantage of the octane enhancement potential of MTBE, given their refinery configuration. While some estimates put the cost of lower-octane gasoline at 0.5 to 1.25 cents per gallon lower than the regular grade, they do not include the additional storage and handling costs that the practice requires (Minnesota, 1997). We do not estimate a potential savings due to the octane enhancement value of MTBE.

Direct Costs of using Ethanol in CaRFG2

Estimating the hypothetical extra cost associated with a scenario in which ethanol would become the principal oxygenate in use in California, either as a result of a mandate or as the default in the wake of a ban on MTBE, is not a simple task. Since gasoline oxygenated with ethanol represents a small fraction of all the gasoline sold in the state, a comparison of retail prices in California is not an accurate indication of cost differentials. The same is true of wholesale gasoline prices. Rather, we examine wholesale and retail prices for gasohol (gasoline with ethanol) in other regions of the nation, in order approximate the magnitude of this cost. However, such comparisons invariably are influenced by other factors, including proximity to ethanol production plants, refineries and distinct regional patterns of demand. Another approach is to consider the additional cost that California refiners would incur by having to purchase the necessary ethanol on the market to meet California's demand if MTBE was banned.

Retail Prices

The Minnesota report (1997) evaluated the efficacy of the state's ethanol subsidy programs. The report examined retail and wholesale gasoline price data for a large multi-state region that included Minnesota and 14 other Midwestern states from Oklahoma to the Canadian border (Petroleum Administration District II). Minnesota uses almost exclusively gasohol and is the only state in the region that requires the use of oxygenated gasoline (2.7% oxygen content). Thus the PADD II price data for oxygenated gasoline represents prices of gasohol for Minnesota. Data from the period from October 7, 1996 through January 20, 1997 were evaluated. Since the premium paid in Minnesota reflects the price paid for federal oxygenated gasoline which contains more oxygenate than the CaRFG2 requirements, 2.7% versus about 2.0%, we might expect this premium to be somewhat high. Nevertheless, the premium paid for gasohol in Minnesota relative to conventional average prices of gasoline (PADD II all grades considered) ranged from 2 to 9 cents per gallon, and averaged 5.5 cents per gallon (Minnesota, 1997). This range corresponds to an annual cost to California consumers of between \$278 million and \$1.3 billion. However, we do not consider this to be the most accurate estimation of the cost differential to California's consumers.

Wholesale Prices

The Minnesota study (1997) also looked at wholesale oxygenated and conventional gasoline prices (net of taxes) for the nation, the PAD II District and for Minnesota in 1995. Oxygenated gasoline is about the same price in Minnesota as in the nation as a whole, suggesting that the choice of oxygenate does not strongly affect the ultimate retail price, at least given the state subsidies ethanol enjoys in Minnesota. The wholesale premium paid for oxygenated gasoline in Minnesota is however about half that of the national average. This is a reflection of the fact that the price of conventional gasoline in Minnesota is significantly higher than the nation as a whole, due to the fact that most of the conventional gasoline used in Minnesota is sold outside of the Minneapolis/St. Paul area where distribution costs are higher and there is less retail competition. The premium paid for oxygenated gasoline in 1995 in the nation as a whole and the PAD II District was about 5 cents, while in Minnesota this premium was about 2 cents per gallon (Minnesota, 1997). Since the only oxygenated gasoline consumed in PADD II is sold in Minnesota, the premium calculated for the region probably is based on a more reliable conventional gasoline price baseline than the intra-state comparison. A premium of 5 cents per gallon implies an extra cost to California consumers of $695 million per year.

Ethanol Demand-based Price Analysis

Calculating the extra cost to suppliers of California gasoline based on the probable market prices for ethanol under a complete MTBE ban represents the most promising approach to estimating the directs costs associated with the hypothetical conversion to ethanol as the primary oxygenate in the state. There are several important factors to consider. The first is the proportions of the mixture to be considered. While we are primarily interested in the cost premium associated with a mixture that has a 2 % oxygen content (5.7% ethanol), it may be reasonable to consider another scenario as well. The recently extended federal ethanol subsidy, which operates as a partial exemption to the Highway Tax on gasoline, is set at 5.4 cents per gallon for a 10 % ethanol blend. A 10 % ethanol blend results in a mixture with oxygen content of 3.5 %**.** Consequently, under any scenario whereby producers are compelled to use ethanol, it is likely that they might choose to blend ethanol at 10 % in order to take advantage of the federal tax exemption to the full extent. In addition, in order to take advantage of the federal RVP waivers for gasohol (ethanol significantly increases the vapor pressure of fuel and without such a waiver it would be difficult for refiners to meet regulatory specifications), ethanol must be blended at the 10% level. However, current RVP restrictions effectively preclude refiners from blending with 10 % ethanol. CARB is however considering the possibility of granting a waiver of 1 psi for gasoline blended with 10% ethanol thereby allowing CARB RFG to have up to 8 psi RVP. Consequently, it is prudent to consider a 10% ethanol blend as well as a 5.7% blend when attempting to calculate the direct costs that would be associated with a statewide switch to ethanol. We have chosen to designate these two scenarios as “no waiver” (5.7 % blend) and “waiver” (10 % blend), respectively.

The supply of ethanol is a crucial consideration. In fact, it is not certain that domestic production of ethanol could meet the additional demand created by the use of ethanol as the only oxygenate for California, specially in the short-run under the waiver scenario. The effects of this new demand on ethanol price must be carefully considered and investigated further. Based on a total annual gasoline consumption in California of approximately 905,000 barrels per day (b/d) and oxygenation with ethanol at 5.7% and 10% ethanol, California's conversion to ethanol as the primary oxygenate would result in around 57,000 b/d or 95,000 b/d of total ethanol demand. When taking into account the vehicle mileage loss associated with ethanol, this demand might approach 100,000 b/d under the waiver scenario. Total potential domestic capacity for ethanol production is about 107,000 b/d. Domestic demand is approximately 80,000 b/d, leaving an excess capacity of around 30,000 b/d which could be made available for California's use. This can create an ethanol shortage in the short term.

Based on an analysis by the California Energy Commission, California could "bid away" blocks of ethanol capacity from other regions based on a price premium (CEC, 1998b). The first block is from current unused ethanol production capacity. California's additional demand may be enough to compel ethanol producers to produce at full capacity. It is not likely that eliciting this additional production would result in a noticeable price per gallon premium. However, it would be necessary to factor in transportation costs of approximately 15 cents per gallon. (CEC, 1998b). Next are blocks of ethanol capacity which are currently used in other areas but which could potentially be bid away were the price to rise high enough. The cheapest blocks will be those which are closest to California and hence will incur the smallest transportation costs. The first such block might come from the other PADD V states. The CEC (1998b) analysis indicates that a price of $1.60 per gallon of ethanol is the price at which ethanol would begin to lose its competitive advantage with respect to MTBE. Therefore, this would be the price at which California suppliers could begin to bid ethanol away from neighboring states. Transportation costs for this block would be approximately 3 cents per gallon. The next block available would be from the Rocky Mountain states (PADD IV). A price of $1.60 per gallon would also be necessary to attract this block. However, transportation costs now add some 6 cents per gallon. In the "no waiver" scenario, the final block of ethanol could be bid away from the Midwest. Since ethanol is used in the Midwest not only as an oxygenate but also as a gasoline extender, the price required to bid this block away is slightly higher than the previous two, or $1.64. Transportation costs add approximately 15 cents per gallon. Under the "waiver scenario" an additional 32,000 gallons can be bid away from the Midwest. The final 39,000 gallons which would be required must be imported from abroad, most likely from Brazil. This block would require the price to rise to $2.22 per gallon which includes transportation costs and tariffs. This offset is calculated based on an average wholesale price of conventional gasoline in California in 1996 of 72 cents per gallon (US DOE, 1996).

The estimated unit price increase ranges from 1.6 cents per gallon to 4.5 cents per gallon. This method predicts a total cost to Californian consumers of $220 million for the “no waiver” scenario and $608 million dollars for the “waiver scenario.” We consider these figures to give the most accurate estimate for the range of costs likely to be borne by California consumers if ethanol becomes the primary oxygenate.

Vehicle Mileage Decrease

Ethanol has an energy content that is significantly less than that of the ethers or gasoline on a per volume basis. The effect of this difference on the overall vehicle mileage of RFG is moderated by the fact that oxygenation at the 2 % level requires less ethanol than MTBE (5.7% versus 11%). Reductions in vehicle mileage of up to 3% relative to non-oxygenated fuel have been estimated (NSTC, 1997). Clearly if vehicle mileage drops and we assume that the demand for miles traveled remains constant, we might expect overall consumption to increase commensurately, at significant cost to the consumer. We have calculated the cost associated with this loss of vehicle mileage separately. Given that the current annual statewide consumption of gasoline is on the order of 13.9 billion gallons per year (905,000 b/d) we can estimate an increase in consumption of 209 million to 417 million gallons (CEC, 1998b). This corresponds to a potential cost associated with the loss in vehicle mileage of $288 to $575 million per year to California consumers for the 5.7% and 10% ethanol content.

No significant effects in terms of maintenance or decreased engine performance have been documented for gasohol at 5.7% and 10% ethanol content.

Octane Enhancement

Ethanol has an octane rating of about 115 and consequently can raise the octane value of the fuel with which it is mixed. However, not all producers are in a position to be able to take advantage of this effect, since their base gasoline may already have a high enough octane level. This effect was deemed to be variable and small, and hence the benefit has not been calculated.

Direct Costs of non-oxygenated CaRFG2

The additional cost of producing a non-oxygenated fuel can be estimated by considering a weighted-average analysis, similar to calculations by CEC (1998b) for ethanol blends (according to discussions regarding possible blends with industry representatives from Chevron). We consider a toluene-enriched mixture that is 90% gasoline blended with 10% toluene. As a first estimation we consider the U.S. Gulf Coast spot price for commercial toluene of 54.5 cents per gallon (Platt's Petrochemical Market Wire, 1999). We consider a price of 72 cents per gallon for unblended reformulated gasoline. This gasoline price results in an approximate wholesale cost of 70.3 cents per gallon. Based on this simple analysis we conclude that there would be a savings of between 0 to 2 cents per gallon associated with the use of non-oxygenated gasoline. This simple analysis clearly ignores the effect that a 100% switch to toluene-based CaRFG2 would have on toluene prices. Nevertheless, it appears that non-oxygenated gasoline might not be any more costly than oxygenated fuels, and could produce significant savings.

Toluene production capacity is limited by other uses of toluene at the individual refineries, as a primary petrochemical. There is probably not enough toluene production capacity in California to meet the demand of 100% non-oxygenated CaRFG2. It is likely that toluene would have to be imported to satisfy the demand, which would result in transportation and distribution costs. However, given the margin between toluene and gasoline prices, toluene landed costs at the refinery could rise by 16 cents per gallon (almost 30%) before the price of gasoline would increase. We have not evaluated whether there is enough worldwide capacity to meet California's toluene demand or the potential effect of supply shortage on price. We estimate that even under a very conservative scenario, the price of non-oxygenated CaRFG2 will only increase 1 to 2 cents per gallon if California chooses to convert 100% to this gasoline. The increase corresponds to an increase in price for toluene landed of approximately 70%. Thus, our unit price estimates range from –2 cents to +2 cents per gallon. For Californian consumers, this means a potential cost savings of $280 million to a net cost $280 million per year.

The energy content of non-oxygenated gasoline will increase by about 0.8 to 1.2% depending on the amount of toluene used, given the higher energy content of toluene relative to gasoline. This means that if miles traveled per year remains constant, Californians would consume between 110 million and 170 million fewer gallons of gasoline per year. Based on an average retail price of $1.38 per gallon this corresponds to a savings of between $150 million and $230 per year.

Other Studies of Direct Cost Increases

Several other studies have attempted to analyze the direct costs associated with the use various fuel blends. A report produced by the California Energy Commission in particular provides a detailed cost evaluation of alternative oxygenates, as well as a no oxygenate fuel blend, which could be used in lieu of MTBE in gasoline in California (CEC, 1998). For each alternative, the CEC estimated the potential savings costs or savings to the public in the form of increases or decreases in retail gasoline prices for each alternative when compared to MTBE. The CEC arrives at an estimate of the costs associated with ethanol use that is substantially larger than our own. However in order to assess the validity and actual magnitude of this discrepancy it is crucial to recognize how the scope and approach of the CEC study differ dramatically from those of our analysis.

In a general sense, the CEC study was a narrow, focused and intricate assessment of the direct costs associated with alternative oxygenates. On the other hand our direct cost analysis was clearly part of a broader analysis which attempted to comprehensively account for all the potential costs associated with the use of three specific fuel alternatives. The focused and detailed nature of the CEC study motivated the approach that it employed. It relied heavily upon the use of refinery models to simulate the statewide refinery operations that would be required to meet projected daily average gasoline demand under the scenarios considered. In this sense it explicitly considered the capacity of California's refiners as part of the overall cost equation, and how this capacity might influence the supply and price of different oxygenated fuel alternatives.

Another important difference in approach was that while for simplification we conducted a static analysis, the CEC's study was in some respects dynamic. They segregate the period of adjustment in refiner capacity and oxygenate supply following the hypothesized adoption of an alternative oxygenate into three distinct periods, the near term, the intermediate term and the long term. They first conduct an evaluation of the minimum time frame within which alternatives could be substituted for MTBE without resulting in insurmountable disruptions of gasoline supply. The near term analysis considers the cost of immediately replacing MTBE with an alternative, before any adjustments could be made on the part of refiners. The intermediate and long term scenarios on the other hand evaluate the costs of phasing out MTBE over a three and six year period respectively. Three years is assumed to be sufficient to allow the markets for alternative oxygenates to develop and attain a new level of supply and demand balance. Furthermore, while refiners would not have time to undertake major equipment modifications they would have time to modify certain process operations, improving their ability to meet demand. In the long term refiners would not only have time to undertake minor debottlenecking but would also have had time to make major process modifications such as equipment replacement or capacity expansion. Consequently, the cost impacts for consumers as calculated by the CEC are directly related to the period of time permitted for phasing out MTBE.

These differences in approach lead to some difficulty in attempting to compare our results to those of the CEC. Clearly one additional difficulty stems from the fact that our costs were calculated relative to a baseline of conventional gasoline while those of the CEC are figured as incremental costs due to the conversion from current MTBE gasoline to an alternative. It is possible to compare the analogous incremental costs between MTBE and ethanol, for example, that our study implies to those calculated by the CEC. However, the time horizon analysis employed by the CEC further confuses such a comparison. For example, our static approach assumed that the conversion to ethanol was complete and immediate in that our analysis was based on current gas consumption levels. However, we also assumed that a state of equilibrium had been achieved where both infrastructure adjustment and changes in refinery capacity were both complete, and that any fixed costs associated with these adaptations were insignificant. In contrast the CEC near term analysis did not allow for such adjustments, while the CEC long-term analysis incorporated gasoline consumption levels six years hence. These fundamental differences in assumptions preclude a straightforward comparison between ethanol calculations.

The no oxygenated fuel scenario that the CEC considers is markedly different from the non-oxygenated option that our study includes, which is Ca-RFG2 compliant. The CEC’s no oxygenate analysis does not rely on displacing oxygenate with toluene as is the case with our non-oxygenated scenario. Instead, the displaced oxygenate is assumed to be replaced with expensive high-octane import components, mostly alkylates. This results in the CEC’s no oxygenate scenario being one of the most costly options it considers. This difference, based on different assumptions about legislative constraints precludes a comparison altogether. Consequently, the only common alternative where comparison of any sort between the CEC and our study might be valid is ethanol.

In summary, our analysis of direct costs is based on very different assumptions than those upon which the CEC’s assessment is based. Where we assume refinery output to be unconstrained, their analysis incorporates simulated capacity constraints. We use the simpler static analysis in contrast to the dynamic analysis employed by the CEC. An offshoot of this assumption is that we do not include the costs associated with adjusting capacity. Also, our study uses conventional gas as a baseline and the CEC uses MTBE. Finally the assumptions regarding the legislative framework for blends that do not use oxygenates are not common.

The CEC does not attempt to quantitatively estimate the increase in cost associated with an immediate (near term) phase out of MTBE and adoption of ethanol. A conversion undertaken this hastily is assumed to result in severe price shocks. The intermediate term analysis results in an incremental cost estimate relative to MTBE of between 6.7 and 11.7 cents per gallon. The CEC long term analysis concludes that the incremental cost of phasing out MTBE over a six year period and replacing its use with ethanol is between 1.9 and 2.5 cents per dollar or in aggregate, between 298 and 392 million dollars per year. These figures include costs associated with fuel efficiency losses relative to MTBE. To get an idea of how the CEC numbers differ from ours in magnitude, the long term analysis, given its common assumptions concerning equilibrium represents the best comparison. Our analysis (Table 4) however suggests that the total direct costs of ethanol are some 100-180 million dollars *less* than those of MTBE.

The assumptions upon which the CEC calculations are based are not similar enough to ours to warrant their explicit inclusion in our balance sheet. We do however believe that they suggest the scope and assumptions of our analysis may have led us to understate the costs associated with ethanol, perhaps by as much as 600 million dollars. While this is a substantial figure, we feel that given the broader purpose of our study it does not undermine our overall results. And in fact Table 4 indicates that even a discrepancy of this magnitude is overshadowed by the other cost categories associated with MTBE.

Cost of Water Treatment

Groundwater Contamination

MTBE can contaminate groundwater when significant amounts of gasoline containing MTBE are spilled on or below the ground surface. The two main sources of such gasoline spills are leaking from underground storage tanks (UST's) and failure of pipelines. Once in the ground, MTBE is more mobile and longer lived than other components of gasoline. MTBE's mobility is due to its highly solubility (NSTC, 1997), allowing it to preferentially dissolve in water and move with the relatively quickly flowing groundwater. Its long life is due to its slow rate of degradation in natural conditions (Squillace et al., 1996). Together, its high rate of mobility and low rate of degradation allow even small MTBE spills to contaminate large areas for long periods of time. Making matters worse, humans can detect MTBE in drinking water at very low concentrations, in the range of 5-15 ppb. Together, these characteristics make MTBE contamination particularly problematic, and drive up the costs of the treatment of polluted sites.

To estimate the statewide costs of cleaning groundwater contaminated with MTBE, we determine approximate values for the following items:

1. the unit cost to characterize to develop a remediation plan for a contaminated site,
2. the unit cost of water treatment for the range of conditions likely to be encountered,
3. the number of sites to be treated, and
4. the amount of time required to remediate a site.

The specifics of this methodology, as well as a detailed description of the results, is described in further detail in Keller, et al. (1998a). Due to uncertainty in the some of the necessary primary data, the resulting water treatment cost estimates are given as a range of values. The results are summarized in the following Table 8.

	Low Estimate	High Estimate
Older UST sites	$320 million	$1030 million
Future UST sites	$7 million	$370 million
Pipelines	$5 million	$10 million
Public Wells	$2 million	$36 million
Private Wells	$1 million	$4 million
Surface Water	$4 million	$30 million
Total	$340 million	$1,480 million

[1] relative to conventional gasoline

Table 8. Aggregate Annualized Cost of Water Treatment For MTBE Contaminated Sites[1]

Because ethanol in groundwater tends to biodegrade fairly rapidly, we do not expect extra costs to be associated with the clean up of a site contaminated with CaRFG-ethanol relative to a site contaminated with conventional gasoline. Similarly, we expect a negligible cost differential for treating a site contaminated with non-oxygenated gasoline relative to conventional gasoline. These conclusions are discussed further in Keller, et al. (1998a).

Costs of Alternate Water Supply

Rather than treating contaminated water, some public utilities choose to procure water from an alternate supplier, as the city of Santa Monica has done. We base our estimation for the costs of alternate water supplies on the price that Santa Monica pays the Metropolitan Water District: $440 per acre-foot, or $1.65 per thousand gallons (Rodriguez, 1997). Estimating that 20% of contaminated water supplies would be replaced by alternate sources, and that approximately 3 to 90 billions of water will be contaminated each year, we conclude that the total annual cost of water from alternate supplies would be $1 million to $30 million. Such an increase in demand for water would likely lead to a price increase. We do not attempt to speculate the size of this increase, resulting in a slightly more conservative estimate.

Since we do not project increases in drinking water contamination for ethanol-based gasoline formulations or non-oxygenated gasoline, the costs of alternate water supplies in these scenarios is zero.

Water Monitoring Costs

Surface Water

Recorded monitoring costs from the East Bay Municipal Utilities District (Tikkanen, 1998) were used to estimate California's statewide annual surface water monitoring cost.

The estimated cost per year, per reservoir is $10,000 to $25,000. This cost is based on the number of samples taken per month (varying substantially, but typically around 10), the analytical cost ($50 to $100 per sample), and the cost of collection ($500 to $800 per month), which includes labor and boating expenses.

Although there are 765 reservoirs used for drinking water, we estimate that there are only between 100 and 150 reservoirs that allow recreational boating. MTBE monitoring is typically only done on these reservoirs which supply drinking water and allow recreational boating.

Based on these parameters, the total estimated annual cost to California of monitoring surface water is $1 million to $4 million.

Ground Water

Groundwater near an underground storage tank (UST) containing gasoline is monitored, whether or not that gasoline contains MTBE. Therefore, we do not consider any additional costs to California of monitoring these USTs.

In light of the MTBE groundwater contamination in Santa Monica, it is likely that drinking water suppliers who use groundwater sources may increase the frequency of monitoring their sources, especially those sources in close proximity to an MTBE-containing UST. According to 1998 data from the California Department of Health Services (CAL-DHS), there are 3,756 drinking water source wells. CAL-DHS requires sampling every three years. If each of these wells were sampled annually, we estimate that this would result in an increased annual cost to California of between $1 million and $2 million (Keller, et al, 1998a).

Recreational Costs

One policy option to rapidly reduce the impact of motorized boating on lakes and surface water reservoirs is to ban all watercraft that use gasoline with MTBE. As Reuter et al. (1998) point out, different engines used on watercraft emit significantly different amounts of unburned gasoline (with MTBE) to the environment. To assess the value of the recreational activities that would be lost with these boating restrictions, we first need to estimate the value of recreational boating. For this valuation, we use the Travel Cost Method, which incorporates estimates of costs associated with the trips to the recreational sites (lakes and reservoirs), the driving time cost associated with these trips, and the entrance fee and fuel prices that are necessary to enjoy the recreational activities.

The travel cost is a measure of demand for environmental quality and goods and thus we can assume that it depends only on the characteristics of the lake, as they relate to recreation. Based on this assumption, we classify 115 reservoirs used for both recreational gasoline powered boating and water supply into several groups (See Appendix B for details on specific reservoirs). The classification is based on two reservoir characteristics: boating status (Dirksen and Reeves, 1993), and reservoir size (CAL-DWR, 1998). For boating status, we use three classes: (a) major sites, (b) well-equipped sites, and (c) usual sites. The capacity of reservoirs is also classified into three groups: (d) large, (e) medium, and (f) small. We allocate a point to each category and combine them into five classes as shown in Table 9.

Categories according to boating status	Number of Reservoirs	Points	Categories according to reservoir sizes	Number of Reservoirs	Points
a) Major	12	3	d) Large	15	3
b) Equipped	25	2	e) Medium	59	2
c) Usual	79	1	f) Small	42	1

⇩

Classes	Sum of points	Number of Reservoirs
1	6	7
2	5	10
3	4	19
4	3	42
5	2	38

Table 9. Classification of Dual-Use Reservoirs and Lakes

We assume the travel cost increases by a constant factor R as the class becomes higher by one (5 as the lowest and 1 as the highest class), as in the following equation:

$$\text{(travel cost for } N^{TH} \text{ class)} = R^{5-N} * \text{(travel cost for class 5)} \qquad (1)$$

where R is constant and $N=1, 2, 3, 4, \text{and } 5$.

With this assumption, we estimate the travel cost for each class and hence the total travel cost by obtaining those for the highest class (class 1) and the lowest class (class 5).

Estimate of travel cost for class 5 reservoirs

The following example from Santa Clara County illustrates the calculation of travel costs for the various classes of reservoirs. According to the data for Calero Reservoir in Santa Clara County (CAL-DWR, 1998), a class 5 reservoir, 4,391 boats launched in the one-year period from April 1st, 1997 to March 31st, 1998. Based on information from Santa Clara County Parks, 45% of the total visitors bought an annual permit ($50) and others paid the daily boat launch fees of $10. It is estimated that those who bought annual permits visited Calero Reservoir seven times a year on average. The total fee can be estimated as follows:

Total fee

= [number of annual permits issued] x [price of annual permit]

+ [number of daily entrance fee paid] x [daily launch fee]

= [4,391 x 0.45 / 7] x [$50] + [4,391 x 0.55] x [$10]

= $38,264

Assuming an average boat uses 10 gallons of gasoline per day, which costs $1.20 per gallon, we then obtain the total price of gasoline that is used for boating through following calculation:

Total gasoline price for boating

= [4,391 boats] x [$1.20 per gallon] x [10 gallons]

= $52,692

The Parks Department notes that 90% of the boaters are from Santa Clara County, driving an average of 5 miles to recreate at the reservoir. The remaining 10% of the boaters drive 100 miles on average. Assuming an average 20 miles per gallon for cars, the driving costs are:

Driving costs

= [4,391 x 0.90 cars] x [5 miles] x [$1.20 per gallon] / [20 miles per gallon]

+ [4,391 x 0.10 cars] x [100 miles] x [$1.20 per gallon] / [20 miles per gallon]

= $1,186 + $2,635 = $3,820

We assume that on average there are three people per boat, with jobs whose wages are $15 per hour (we use a range of wage rate from $15 - $25) to account for a variety of recreationists. We also assume that driving 5 miles takes 15 minutes and driving 100 miles takes 2 hours. The driving time cost can be obtained as follows:

Driving time cost

= [4,391 x 0.90 cars] x [3 people] x [0.25 hours] x [$15 per hour]

+ [4,391 x 0.10 cars] x [3 people] x [2 hours] x [$15 per hour]

= $44,459 + $39,519 = $83,978

The total travel cost for a reservoir is the sum of fees, gasoline use for boating, driving costs and time cost:

The total travel cost

= Fee + Gasoline price for boat + Driving cost + Time cost

= $178,754

The total travel cost per year for the Calero Reservoir is estimated at $178,754 for the $15 per hour wage rate and $234,739 for $25 per hour wage rate. Therefore, the travel cost for reservoirs of class 5 is approximately $180,000 at the $15 wage rate.

Estimate of travel cost for class 1 reservoirs

For estimation of the travel cost for class 1, we used the data of Lake Tahoe. In the three-month boating season (June through August) of 1998, the total number of persons who visited Lake Tahoe for boating purpose was 293,678 and the number of boats was 92,400 (Reuter et al., 1998), but unlike the Calero Reservoir, numbers of visitors from different places are not available. Since the travel cost directly depends on the travel distance, we first estimate the numbers of visitors for different distances from Lake Tahoe using the *gravity model.*

Gravity Model Estimation of visitors from different distances

The gravity model and its application

The so-called "gravity model" has been widely used by planners and engineers to forecast regionally distributed transport demands associated with implementation of development plans such as transportation investments, land use plans, and residential developments (Hurst, 1974; Black, 1981; Robinson and Bamford, 1978). The gravity model, so named because its structure is analogous to Newton's law of universal gravitation, calculates the number of trips generated between two sites by attraction factors of both sites as well as the distance between two sites, as in the following equation:

$$T_{ij} = C\frac{P_i^{a} Q_j^{\ b}}{D_{ij}^{\ g}} \tag{2}$$

where T_{ij} : number of trips between zone i and j

P_i : attraction factor of zone i

Q_j : attraction factor of zone j

D_{ij} : distance between zones i and j

a, ß, g, C : parameters

Economic indexes such as population and total area of office buildings are generally used for the attraction factors. The advantage of the gravity model is in that it can represent the inverse relationship between the number of trips and the distance (Dickey, 1975).

To estimate the number of visitors to Lake Tahoe from different places, we used the typical values of parameters; *a=ß=1* and *?=2*, which make the equation exactly the same to that of the formula for the universal gravitation. Also, in this case, the trips have only one destination so that *j* doesn't vary and can be dropped. Consequently, *Q* is a constant that measures combined attributes of Lake Tahoe. *i* is an index that designates zones of origins of the trips, and for P_i we adopted the population of the zone *i*. For D_i, we consider the distance from the population center of zone *i* to Lake Tahoe. We then have the following equation:

$$T_i = C\frac{P_i Q}{D_i^2} = C'\frac{P_i}{D_i^2} \qquad (3)$$

where T_i : number of visitors of Lake Tahoe from zone i

P_i : population of zone i

D_i : distance between zones i and Lake Tahoe

$C' = CQ$

The parameter *C'* is obtained by the following calculation;

$$\sum_i C'\frac{P_i}{D_i^2} = 293{,}678 \qquad (4)$$

$$C' = \frac{293{,}678}{\sum_i P_i / D_i^2}$$

and the number of visitors from zone *i* is obtained by the equation (3).

Data and calculation

For simplicity, we considered only counties in California and Nevada whose populations are greater than 50,000 and divided into 6 zones in terms of their distance to Lake Tahoe. We get values for input variables and the estimated number of visitors for each zone by calculation using equations (3) and (4) as depicted in Table 10.

i	Counties involved	Population (P_i)	Distance to Lake Tahoe (D_i) in miles	Estimated number of visitors (T_i)
1	Placer, El Dorado	365,500*1	33	57,772
2	Sacramento, San Joaquin, Stanistraus, Butte, Yolo	2,491,000*1	76	75,364
3	San Francisco, San Mateo, Santa Cruz, Santa Clara, Alameda, Contra Costa, Solano, Napa, Sonoma, Marin, Merced, Madera, Monterey, Fresno, Tulare, Kings, Shasta, Humboldt	9,211,400*1	152	69,671
4	San Luis Obispo, Kern, Santa Barbara, Ventura, Los Angeles, San Bernardino, Orange, Riverside, San Diego, Imperial	20,340,700*1	390	23,430
5	Washoe, NV	305,792*2	29	65,789
6	Clark, NV	1,106,047*2	343	1,653

*1 Estimates for January 1st, 1998

*2 Estimates for July 1st, 1997

Table 10. Data and Estimates for Zones

Following the same processes to the case of the Calero Reservoir (class 5) and using 92,000 as the number of boats, 293,678 visitors, and 3.178 persons in average on a boat and on a car, the total travel cost of visitors for boating in Lake Tahoe is estimated as $10,641,000. However, the boating season in Lake Tahoe only lasts three months out of a year, which is not likely the case for other lakes and reservoirs – in those located in south of the state or in non-mountainous areas the boating seasons are longer. We estimate $16,000,000 (approximately 1.5 times greater than $10,641,000) as the travel costs for lakes and reservoirs in class 1.

Estimation of the state-wide total travel cost

Based on the information for Calero Reservoir (class 5) and from Lake Tahoe (class 1), we estimate the value for the parameter *R* in equation (1) and the total travel cost for each class, as shown in Table 11. The two reservoirs place a lower and upper bound on our estimate.

$$R = \sqrt[4]{\frac{\text{travel cost for class 1}}{\text{travel cost for class 5}}} = \frac{\$16{,}000{,}000}{\$180{,}000} = 3.0705$$

Classes	Travel Cost for each reservoir	Number of reservoirs	Total travel cost for each class
1	$16,000,000	7	$112,000,000
2	$5,210,844	10	$52,108,445
3	$1,697,056	19	$32,244,069
4	$552,694	42	$23,213,128
5	$180,000	38	$6,840,000
Total		115	$226,405,642

Table 11. Total Travel Cost per Reservoir and Class (assuming a $15 per hour wage rate)

The state-wide estimate of the total travel cost for the recreational gasoline-powered boating is approximately $230 to $340 million, based on the range in wages and the different travel cost estimates from the two reservoirs. This figure is an estimate the total value of recreational boating in lakes and reservoirs in the State of California that are also used as drinking water reservoirs. This estimate provides an upper bound on the value of recreational boating that may be lost if all motorized watercraft are banned.

We consider that this cost would not be significant for ethanol-based gasoline formulations or non-oxygenated gasoline, relative to conventional gasoline.

Ecosystem Damages

The concentrations of MTBE that have been detected in lakes and reservoirs are not high enough to expect any damage to biota in aquatic ecosystems (Werner and Hinton, 1998).

Spills may have an ecosystem impact in the immediate area, but, since damages due to a spill would be very similar whether or not the gasoline contained MTBE, the ecosystem damage resulting from these spills is negligible relative to the other costs associated with MTBE.

We estimate that the cost of ecosystem damages due to ethanol-based gasoline would not be significant, relative to conventional gasoline.

7. Discussion of Results: The Appropriate Role of Oxygenated Fuel

The results of the cost benefit analysis, along with a careful consideration of the experience to date with oxygenated fuels, raise serious questions as to the efficacy of fuel formulations in the amelioration of California air quality. State law has required the seasonal use of oxygenated CaRFG2 in a number of air basins since 1996 and recent CARB revisions of the California Reformulated Gasoline Regulations reaffirm this requirement (CARB, 1998d). Furthermore, refiners often choose to supply areas where the use of an oxygenate is not mandated with oxygenated CaRFG2, even outside of the season in which oxygenates are required. This is based presumably on established economies of scale in refining and distribution. However, given the concerns and expense associated with the use of MTBE, or any oxygenate for that matter, a policy which calls for the continued use of oxygenated fuel should be targeted at those areas where benefits of continued use is apt to outweigh any associated ill effects.

A variety of evidence suggests that the use of oxygenated-CaRFG2 can be justified, if at all, only in those regions where carbon monoxide concentrations are of serious concern. We have stated our assumption (for the CBA) that lower CO concentrations has no associated dollar benefit in areas already in attainment of federal CO standards; however in areas that are in non-attainment, CO reductions should still be a policy goal. Depending upon the explicit oxygen content of the gasoline, reductions between 6-16% in CO emissions have been observed in connection with the use of MTBE (Bishop and Stedman, 1989 and Bishop and Stedman, 1990). Furthermore, studies by CARB comparing CO concentrations before and after the introduction of wintertime oxygenated gasoline in several non-attainment areas indicated a 5-10% decrease in CO attributable to the fuel change (Dolislager, 1993 and Dolislager, 1996). The addition of ethanol to gasoline at approximately 10% by volume has also been shown to result in similar reductions. However, the evidence seems to be just as clear that oxygen content does little or nothing to reduce peak ambient ozone concentrations (AQIRP, 1990; AQIRP, 1991a; AQIRP, 1991d; AQIRP, 1992a; AQIRP, 1995a).

Furthermore, as indicated in the AQIRP report, the non-oxygenated formulation produced similar results to gasoline oxygenated with either MTBE or ethanol.

It is also important to recognize that improvements in vehicle technology have and will continue to have a major effect on the reduction of emissions of all pollutants. Even in the case of carbon monoxide emissions, where the use of oxygenated fuels is arguably most effective, potential CO emission reductions are limited. Even when the use of oxygenated fuel is properly targeted at CO reduction, advances in average vehicle technology of the fleet tend to overshadow the effect of fuel formulations.

Given these considerations we believe that it is logical to constrain the use of oxygenated fuels strictly to those regions, which are plagued by excessive levels of carbon monoxide. These regions include the South Coast Air Basin, which has violated the federal 8-hour CO standard of 9 ppm twelve days in 1997, with a maximum peak of 15.5 ppm (CARB, 1999). Any other air basins where CO concentrations were measured to be above the federal standard would similarly be considered to be in non-attainment.

The Verdict on MTBE

The cost benefit portion of the analysis indicates that the use of MTBE costs the state of California on the order of 1.1-3.1 billion dollars per year. This financial burden is imposing, especially given the growing body of evidence that challenges the very air quality benefits attributed to MTBE. This fact, coupled with the serious uncertainty concerning the potential human health effects arising from water contamination, argues for an eventual phase out MTBE use, as well as the use of its close relatives ETBE and TAME. Critics of this conclusion might correctly point out that other just as worrisome uncertainties surround potential replacements such as ethanol or non-oxygenated reformulated gasolines. We believe the weight of this argument to be considerable. This is clearly a strong reason to not endorse the adoption of another alternative oxygenate or formulation for use in the state of California in any sort of a wholesale fashion. However, this is not reason to hesitate to phase out the use of an additive whose expense is already tremendous (see results of CBA, section 6), and as new research concerning health effects comes to light, may prove in the future to be staggering. This is especially the case given the fact that MTBE's benefits for most of the state are at best, dubious.

Given the difficulty involved in precisely quantifying the marginal benefits and costs of MTBE use, especially those related to human and ecosystem health and the tremendous uncertainty surrounding the latter, we believe that simply taxing the use of MTBE stands little chance of successfully internalizing the hidden costs. And as substantial evidence undermines the credibility of benefits originally attributed to its use, we suggest that an eventual ban on MTBE is the appropriate course of action. However, the continued but limited role we envision for oxygenated fuels in CO non-attainment zones means that we must be prepared to advocate the use of alternative oxygenates, at least in limited quantity and for the near future.

There is some debate as to whether, if an immediate ban on MTBE were to take effect, the over-night conversion to some alternative oxygenate would be technically possible for refiners. A ban on MTBE taking immediate effect or a phase out over a period of substantially less than three years could have disastrous effects on the California economy. The California Energy Commission predicts that an immediate discontinuance of the use of MTBE could produce a shortfall of 15-40% of gasoline supply in California (CEC, 1998). Since the presence of MTBE helps to dilute some of the less desirable properties of gasoline (e.g. benzene), removing MTBE from gasoline would leave refiners with a combination of gasoline blending components that would not comply with California regulations. Refiners would have to take additional actions if the use of MTBE were not permitted. One of these actions would involve changing the combination of gasoline blending components mixed to make gasoline. Certain refinery products contain high levels of undesirable properties and would now have to be used in other petroleum fuels or exported for use outside the state. Furthermore refiners might have to seek higher-octane substitutes from outside California to ensure that all grades of gasoline could still be produced. In summary, the loss of California gasoline production capability could dramatically exceed the 11% volume represented by the absence of MTBE alone. The use of ethanol might offset these losses, but not nearly enough, the CEC argues. Even modest shortfalls in available fuel could be expected to trigger substantial price increases the CEC continues to argue. Furthermore there are equipment constraints that might preclude the use of an alternative extensively within at least two years.

The CEC concludes that modifications in refiner capacity and terminal equipment necessary to produce gasoline containing ethanol would require approximately 18 to 24 months.

The CEC study also predicts that, in the case where ethanol was to represent the chief alternative, price increases on the order of 6 to 7 cents per gallon in the intermediate term (a 3-year phase out) might be expected. A phase out of six years, the CEC predicts, would result in a price shock of a mere 2 to 3 cents. The potential for significant price shocks especially in the near term, combined with the need for more research on alternatives, and especially their potential health effects, suggests that a gradual phase out of MTBE is preferable to a ban that would take immediate effect or a rapid phase out. Should incriminating new evidence come to light, appropriate measures could be implemented to dissuade the use of other inappropriate replacements.

Given the CEC estimates of potential price shocks we believe that a prudent phase out should occur over an approximate six-year period. Clearly if the phase out is extended for too long a period, the costs incurred due to additional water resource degradation might become significant. However, the risk to the economy that a shortfall in gasoline production represents is significant enough to merit a phase out of six years. We also believe that enlisting industry support will be an easier task if we opt for a generous phase out period that does not impose undue burdens.

Federal or State Standards?

The use of oxygenated gasoline was originally required as a response to federal mandates. The California Air Resources Board subsequently proposed and was allowed to adopt a set of regulations to reformulate gasoline to slightly different requirements than originally stipulated in the Clear Air Act. California also established and has recently revised a set of standards for determining whether a zone is in attainment or non-attainment for a host of criterion pollutants. The standards differed from the federal standards used for attainment and non-attainment determination. First, the state’s standards generally use different averaging periods to measure the ambient concentrations of a particular pollutant than those stipulated by federal regulations (CARB, 1998a; CARB, 1998b). For instance, in the case of ozone, the state relies upon a 90 ppb threshold as averaged over a one-hour period. The federal regulations call for a two-part standard consisting of both a one-hour average limit, which in the case of ozone is 120 ppb, and an eight-hour limit, which is 80 ppb for ozone. For carbon monoxide, California, like the federal government, also employs both the one-hour and eight-hour averaging time approach. Both the state and the federal government eight-hour averages stipulate a maximum ambient concentration of 9 ppm. The state one-hour standard is more stringent than the federal (35 ppm versus 20 ppm). While clearly the eight-hour and one-hour standards are devised to protect against different exposure levels, it is generally accepted that the state Air Resources Board, in emphasizing shorter averaging times (not only in the case of ozone but also other criterion pollutants) chose to provide a wider margin of safety than provided for by the national standards. The shorter averaging times place what may be an especially high premium on cutting spatially and temporally concentrated peak emissions. Furthermore, state standards need only be exceeded once at a particular monitoring station in a particular region during the calendar year for that region to be declared in non-attainment. Federal standards however require that exceedances be recorded on four different dates over a three-year period within any region for non-attainment designation (Merrifield, 1998).

While we support the goal of superior air quality that the stringency of the state standards relative to the federal standards implies, we believe, given the number of zones that remain in federal non-attainment, that meeting these federal standards first should be paramount. Complying with federal standards is even more pressing and challenging a goal when projections for growth within many state regions and the expected increase in number of zones in federal non-attainment are considered. Acting on this belief, we have relied upon the federal attainment and non-attainment classification standards in designing the regional aspects of our policy recommendations.

The Zones

We examined the current federal attainment and non-attainment zones for two important criterion pollutants, ozone and carbon monoxide. While the regional units to which both federal and state standards are applied are air basins (state defined entities which frequently cross county lines) we have chosen to use the county itself as the fundamental regional unit. This decision is based not so much on any simplification of the classification process but on the ease and clarity of implementing policy on a local level. In cases where federal designations (which apply to state defined air basins) result in part of a county being labeled non-attainment while another is classified as attainment, we have chosen to designate the entire county as non-attainment. In most instances where this is the case, the bulk of the population resides in the federally designated non-attainment portion. For this reason, designating the entire county as non-attainment should not generally impose undue hardship on large numbers of people not responsible for the county's poor air quality.

For the purposes of our proposed course of action regarding MTBE and fuel formulations in general, we have defined three zones (Figure 5). Type I Zones are those characterized by the most severe poor air quality and by definition are those that are in federal non-attainment for both ozone and carbon monoxide. Based on our application of federal standards to the county level in 1998 this designation is applied to four counties, Los Angeles, Orange, San Bernardino and Riverside. Federal standards place the South Coast Air Basin in non-attainment for both CO and O_3. While the South Coast Basin incorporates the whole of L.A., Orange and Riverside Counties it only cuts through a portion of San Bernardino. The remainder of San Bernardino is in attainment for CO but is non-attainment for O_3. Based on this, we have characterized the whole of San Bernardino as Type I. Type II Zones are those where poor air quality is serious, and are defined as those counties which are in federal non-attainment for O_3. The definition results in some 28 counties being designated as Type II. Finally, Type III Zones are those in which air quality is moderate to good, and are defined by virtue of their federal attainment status for both ozone and carbon monoxide.

We anticipate that the California Air Resources Board would re-evaluate the status of each zone on a periodic basis. We further believe the federal procedure of requiring that four exceedances occur within three years is sufficient for the establishment of a trend and advocate maintaining this standard. As soon as a three-year period is identified in which fewer than four exceedances have been recorded, a zone would be eligible for re-designation.

In summary, we propose an immediate ban on the use of MTBE in all gasoline sold in Type II and Type III Zones. Type I Zones will be allowed to continue to use MTBE in gasoline, if the refiners in that region so choose, for approximately six years, subject to certain restrictions detailed below. At the end of six-year grace period, the use of MTBE will

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be banned in these zones as well. However, they will be required to continue to use gasoline which either contains an alternative oxygenate and meets the formulation parameters of CARFG2 or is equivalent to such oxygenated gasoline in terms of emissions. Type II Zones will be compelled to use CARFG2, but without the oxygenate requirement. However, Type II suppliers will be allowed to opt out of this requirement by paying a “formulation waiver fee”, allowing them to supply Type III Zone gasoline in lieu of the regional standard. The minimum standard required of Type III Zones is a slightly modified version of conventional gasoline that is also detailed in the following section.

Type I Zones

Type I Zones will be exempt from the immediate statewide ban on MTBE. Because of the persistent nature of ambient carbon monoxide concentrations in these zones, the continued use of oxygenated CARFG2 or an equivalent is warranted and should be required. In this limited respect we do not recommend changing the status quo regulation of such zones. However, given the development of non-oxygenated RFG blends, which are equivalent to CARFG2-MTBE in terms of emission performance, we believe that any formulation which can be shown to meet such emissions standards under a sufficient variety of technologies and operating conditions should be certified for use in Type I Zones. Furthermore, while it is not our intention to delve into the details of how this certification process might work, we envision that the burden of proving the emission equivalence of the formulation should fall on the refiner.

From the moment that the statewide ban in non-exempt (Type II and Type III) took effect, Type I Zone refiners and distributors would have the option of meeting their current oxygenated CARFG requirement, with their oxygenate of choice. Alternatively, they might provide a blend that was equivalent in terms of emissions to oxygenated CARFG2. Again, we believe that based on the CEC study of alternative oxygenates that the eventual phase-out of MTBE should be accomplished in Type I Zones in a period of approximately six years

Rather than set a rigid schedule for this phase-out that would affect every refiner uniformly, a permit system might be used that would more efficiently result in the desired outcome. The advantage of relying on permits for the phase out is that refiners and suppliers would have more flexibility in terms of the rate at which they were to move away from MTBE. Those suppliers who produce their own MTBE might have costs low enough that, even faced with the prospect of having to buy additional permits, they might continue to supply CARFG2-MTBE for several years at competitive prices. Other suppliers, who face higher costs associated with MTBE might be better served by transitioning more rapidly to other oxygenates and selling their permits immediately.

The government body charged with administering the program in each zone, would first establish the current level of MTBE use. Next, a gradual schedule for the approximate six-year phase out of MTBE would be established. Permits would be issued on the basis of current market share to suppliers in the region. These permits would allow the refiner the right to blend a particular fraction of the annual aggregate MTBE allowance for the zone. Each year, the amount of MTBE use allowed by a single permit would decrease according to a known schedule. As this decrease process proceeded over time, some suppliers would begin to move away from MTBE and sell their permits to those suppliers for whom the combined cost of utilizing MTBE and buying permits was not yet unprofitable. This would allow individual suppliers the time to divest of or convert outmoded capital and invest in the necessary technology and infrastructure to produce and provide alternative formulations.

We recognize that the continued use of MTBE, even for a limited period of time might continue to threaten the water supplies of Type I Zones. We envision that a tax on the use of MTBE might also be incorporated into the regulatory structure of these zones. To link this tax as closely as possible to the externality it would be aimed at addressing, we propose taxing the pre-blending purchase or production of fuel grade MTBE. The appropriate size of the tax could be estimated by quantifying to the extent possible, the expected fraction of every gallon of MTBE that winds up in the zone’s water supply and the cost of cleaning up that quantity. For an example of how this tax would be determined, see appendix A.

Type II Zones

Type II Zones would be subject to an immediate year-round ban on MTBE. As the defining feature of these zones is their federal attainment status with respect to CO, requiring the use of any oxygenate for that matter is not rational, so we do not propose doing so.

However there are possibly distinct advantages to continuing the use of CARFG2 without the oxygenate for air quality in general and for O_3 specifically in Type II Zones. For instance, CARFG2 requires lower aromatic levels than conventional gasoline, which means substantially smaller hydrocarbon emissions (AQIRP, 1990; AQIRP, 1991a; AQIRP, 1991b; AQIRP, 1991c). Similarly, the reduced sulfur content of CARFG has been shown to reduce not only CO emissions but also hydrocarbon and NO_x, reducing the formation of ozone in urban areas (AQIRP, 1991d; AQIRP, 1992a; AQIRP, 1995a). Also, the more stringent RVP, T50 and T90 standards for CARFG result in lower hydrocarbon emissions and reduced peak ozone concentrations (AQIRP, 1991e). Given the preponderance of evidence suggesting the benefits of CARFG2 in terms of reducing ozone, we continue to support its use in Type II Zones.

However, because providing refiners with flexible options is crucial to their cooperative involvement in achieving clean air goals we do not propose to make the use of CARFG2 a rigid requirement. We imagine that some refiners will, because of their presence in Type I Zone markets, have developed economies of scale that allow them to provide CARFG2 without oxygenate inexpensively to Type II Zones. For other refiners, this may not be the case. The option to supply a more conventional gasoline might be attractive economically, especially given economies of scale that could be achieved by a given producer providing conventional gasoline in both Type II Zones and Type III Zones (of course, the more conventional gasoline would still have to meet certain standards, albeit more lax standards; see discussion of Type III Zones). We propose to take advantage of this fact by offering Zone II producers the option to provide CARGF2 in these regions as required, or to supply a modified conventional gasoline meeting the relatively more lax requirements of Type III Zones. Choosing the later option would require the supplier to pay a per-gallon “RFG waiver fee” designed to equate the cost of the two fuel formulations in terms of emissions effect. Because we suggest that improvements in technology are ultimately more effective than relying on fuel formulations, the dividends of this allowance would be used to fund accelerated vehicle retirement programs in the zone. Furthermore, the cost of reducing emissions via vehicle retirement would be the means by which the costs of using the modified conventional versus CARFG2 are framed. Flexibility in the producer’s choice of fuels would ensure that vehicle emissions would be reduced by whichever means were most cost effective, assuming that the per-gallon fee was correctly determined.

The regional air quality board would be charged with establishing the RFG waiver fee, such that either option—selling fuel meeting the stricter standards, or contributing to accelerated vehicle retirement funds—would have a similar effect on air emissions. We envision the California Air Resources Board establishing the guidelines by which this task is accomplished, so that the fee would be determined for each zone in a consistent way. However, setting the value of this fee could be the responsibility of local districts.

Determining the correct amount for the formulation waiver fee is not a simple task, although it is an important one. We feel that an accurate estimation could be determined by considering the emission increase from selling solely the conventional fuel, and then determining the funds necessary to compensate for this increase through a decrease in emissions from an accelerated vehicle retirement program. More specifically, the amount of the formulation waiver fee to correct for ozone might be calculated in the following manner:

1. Estimate the annual vehicle NO_x emissions expected in the zone under both fuel formulation scenarios. The difference in emissions in these scenarios is the amount that emissions would need to be reduced by the voluntary accelerated vehicle retirement program. Note that although there are many pollutants emitted from the vehicle, NO_x is generally the main factor limiting the creation of ozone (National Research Council, 1991), and can serve as a good proxy for other pollutants whose emissions are curtailed by devices such as catalytic converters. Although VOCs, and not NO_x, may be the limiting factor for ozone production in large urban areas such as Los Angeles and Orange Counties, these areas are not expected to be designated as Zone II.

2. Estimate the annual number of vehicles necessary to participate in the accelerated retirement program in order to reduce NO_x emissions by the amount determined above. This calculation would assume the distribution of model-year vehicles participating in the accelerated retirement program, modeled after the previous year's distribution. Removing high-emission cars from the market would encourage the entry of additional new lower-emission vehicles to the market, so only the net gain should be counted. Knowing the typical emissions per vehicle for each model-year (CARB, 1999), and the estimated vehicle replacement rate and emissions per replacement vehicle, one could determine the number of cars necessary to face early retirement each year.

3. Next, determine the per-vehicle cost of the accelerated retirement program. This cost would include the per-vehicle scrap value (i.e., the price paid to the vehicle's owner) and administrative costs, minus the salvage value (i.e., the price received for the vehicle's raw materials, as determined by the market). Because the per-vehicle scrap value is determined by the State, this price will not automatically be efficient in the same sense that it would if the market were to set the price. Instead, the state would follow regular adaptive price setting, resulting in a fairly accurate proxy for the efficient price. As the State aggressively purchases more and more high-emission vehicles, this price would have to increase in response to the decreasing supply of the market. The price would likely increase slowly, and its movements would be predictable. Multiplying the per-vehicle cost times the number of vehicles would indicate the necessary size of the accelerated retirement program fund.

4. Finally, the per-gallon formulation waiver fee would be determined as the total amount necessary to fund the accelerated retirement program, divided by the estimated number of gallons of gasoline sold in that zone.

The formulation waiver fee would need to be updated regularly, annually or semi-annually, to accommodate changes in the vehicle market, changes in the model-year distribution of cars participating in accelerated retirement, and changes in the volume of gas sold in the zone. We recognize that frequent adjustments to the formulation waiver fee might produce a somewhat uncertain and volatile business climate that industry would eschew. However since these adjustments would simply reflect changes in the market value of the emissions differential, and since petroleum producers would not be compelled to pay the fee, we do not believe this program to pose an undue burden on refiners.

Type III Zones

The minimum fuel requirement for Type III Zones is that which we have generally chosen to term modified conventional. Modified conventional would essentially conform to the specifications for average conventional gasoline, as outlined in the introduction. However, given the deleterious effect that sulfur compounds can have on the activity of catalytic converters, we believe that the stricter standards that CARFG2 requires with respect to sulfur content should be incorporated into all gasoline sold in the state, even that in Type III Zones. Modified conventional gasoline would simply incorporate this additional standard. It would also be required to conform to the newer standards for benzene content implicit in the CARFG specifications. This modified conventional gasoline could be sold in Type II Zones by resellers who paid the per-gallon formulation waiver fee, discussed above.

Allowing suppliers in Type III Zones to supply modified conventional gasoline should not in general threaten their attainment status. In most cases, Type III Zones are likely in attainment by virtue of their unique meteorological conditions and lower populations and vehicle density. As originally indicated, the importance of assessing the attainment status of each zone on a regular basis is critical.

Relaxing the fuel standards for Type III Zones would have the important effect of providing incentives for refiners (lower costs and higher profits), consumers (cheaper pump prices) and consequently local governments to achieve Type III status. Modified conventional gasoline could be produced more inexpensively than the stricter formulations of Zones I and II, provided a large enough market existed. This factor is important, but as more zones achieved Type III status the incentive would become commensurately powerful as the size of the market increased.

Summary of Zone Types

Type I Zones

- Not in attainment for carbon monoxide or ozone
- Required to use CARFG2 with oxygenate of choice
- Exempt from statewide ban on MTBE during six year phase out

Type II Zones

- In attainment for carbon monoxide but not in attainment for ozone
- Subject to an immediate ban on MTBE
- Not obligated to use an oxygenate
- Required to use fuel formulations meeting the speculations or emission standards of CARFG2 without oxygenate
- Characterized by flexibility allowing refiners to pay a waiver fee opting out of CARFG2 requirements and instead supply a less stringently constrained conventional fuel

- Formulation Waiver Fee supports accelerated vehicle retirement programs

Type III Zones

- In attainment for both carbon monoxide and ozone
- Subject to an immediate ban on MTBE
- Not obligated to use an oxygenate
- Permitted to use modified conventional gasoline with low sulfur and benzene content

7. Recommendations for the Future

Having concluded that alterations in fuel formulation are not a cost-effective way to improve California air quality, we now turn our attention towards the improvement of vehicle emission-reduction technology. In this section we emphasize both the need for targeting gross emitting vehicles and the need for hastening the introduction of improved automotive technology. We recommend the following options for the improvement of California Air Quality:

1. Reducing the gross emitter problem by instituting
    - Vehicle Retirement Programs
    - Use of Mobile Source Emission Reduction Credits
    - Industry Participation in funding of the aforementioned programs

2. Hastening the introduction of new technology by instituting
    - Adherence to the current LEVII program
    - Adherence to the current CAP 2000 amendments
    - Stricter emissions standards for heavier vehicles such as the Sport Utility vehicle

Moving Away From Fuel Formulations: The Case for Targeting Automotive Technology

Our cost benefit analysis concludes that California's current use of CaRFG2 with MTBE costs the state economy over a billion dollars annually, relative to conventional gasoline. The same amount invested in reducing emissions in new vehicles, and in the accelerated retirement of older vehicles with less-advanced emission reduction technology, would be a more cost-effective means of improving air quality.

Tremendous reductions in vehicle emissions have been achieved by the ongoing introduction of new vehicle technology, such as improvements in catalytic converters and computer monitored combustion control systems. For example, Figure 5 illustrates how NOx emissions per mile traveled have decreased with each new model-year. Carbon monoxide and other pollutants show similarly dramatic decreases in emission rates.

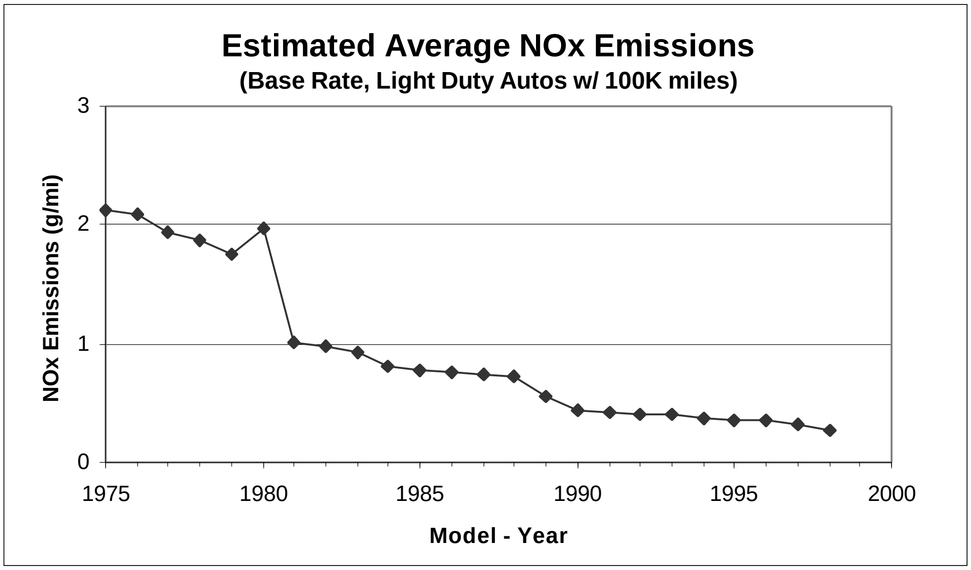

Figure 5. Light-duty-auto emission rates by model year, for vehicles with 100,000 miles. Base rates, shown above, are achieved after the catalytic converter has warmed up (typically after a few minutes). Based upon the MVEI7G model (CARB, 1999).

Start rate is the emission rate immediately after a cold start, base rate is the rate once the engine and catalytic converter has heated up. The rates are based upon CARB's MVEI7G model (CARB, 1999).

These reductions in emission rates due to advances in vehicle technology are drastic: a 75% decrease in emission rates achieved in twenty years. These gains are particularly impressive when compared to estimated effects of improved gasoline formulations. For example, decrease in carbon monoxide concentrations is in the range of a 5-10% (Dolislager, 1993 and Dolislager, 1996).

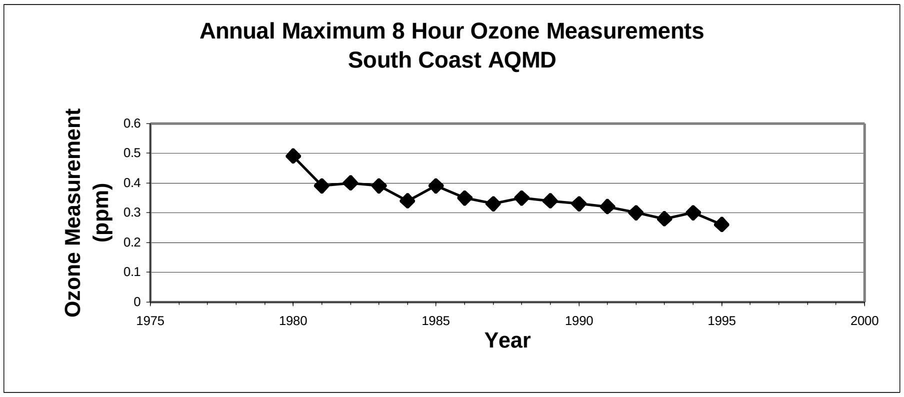

Figure 6. Annual maximum 8-hour ozone measurements for the South Coast Air Quality Management District (CARB, 1999)

Despite this outstanding technical progress, ambient concentrations of pollutants have not decreased as rapidly as these technical advances (for an example of the more modest decreases in ambient air quality, see Figure 6). This lag is due to the fact that all of the cars on California roads are not from the latest model-year, they are a heterogeneous mix of older and newer cars. Thus the effects of each model-year's emission control progress is dampened by the slow turnover of California's automobile fleet. Approximately 35% of California's auto fleet is older than 1990 model-year, as is shown in Figure 7.

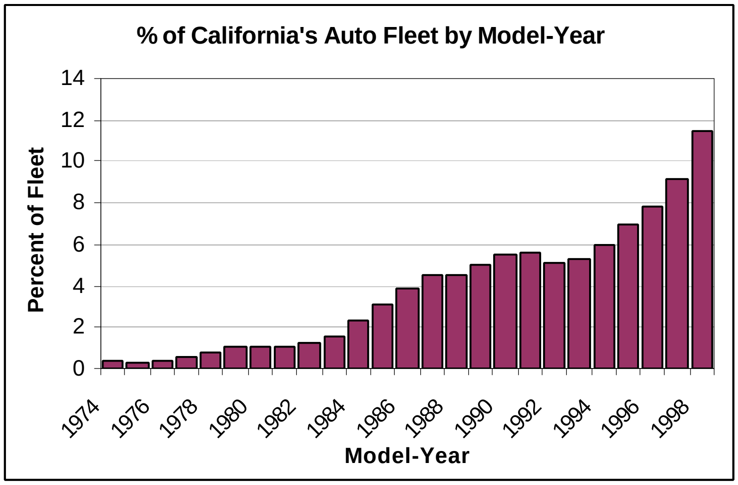

Figure 7. Percent of California's auto fleet comprised by vehicles from each model year, 1974-1998 (DMV, 1999).

Multiplying the emissions per mile for each model year by the size of each model year fleet (and assuming that each model-year fleet logs, on average, the same number of miles), we can estimate the relative contribution of NOx emissions per model year fleet, shown in Figure 8. While pre-1990 cars make up approximately 35% of the automobile fleet, the model estimates that they contribute approximately 67% of the base emissions. The goal of accelerated vehicle retirement programs is to remove from the road these older cars which disproportionately contribute to air pollution.

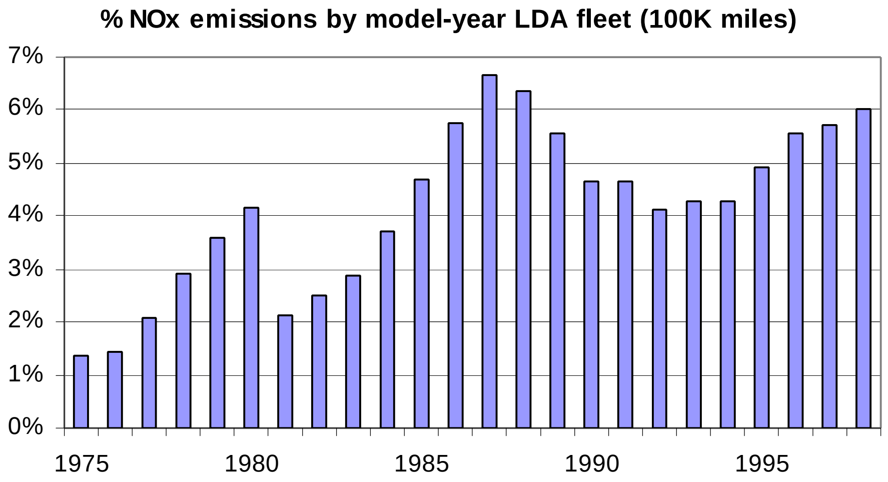

Figure 8. Estimated percent contribution ofNO$_x$ emissions by model-year light-duty-auto fleet (base emissions).

It is clear that methods of achieving clean air other than reliance on fuel formations are important. This section explains how this might be accomplished through the discussion of present and future policies that address automobile technology rather than gasoline formulations. Clearly, many regions have failed to attain air quality that meets the National Ambient Air Quality Standards (NAAQS). Consequently, current non-attainment areas must look for additional measures to achieve further improvements in air quality that will result in attainment designation. Time has shown that gasoline formulations are not a panacea. Current policy with regard to automobile technology must address the existing fleet of cars focusing on those responsible for the disproportionate share of total vehicle emissions.

Examination of the current distribution of automobile emissions as a function of model year of vehicles (see Figure 8) highlights the fact that technology must be addressed in a two-fold manner. Clearly, older vehicles are responsible for a share of emissions disproportionate to their numbers. This is the “gross emitter” problem. Secondly as the number of cars in the state’s fleet increases, new cars represent a larger absolute portion of total emissions. Current efforts and future policies aimed at addressing the former include vehicle maintenance and retirement programs, mobile source emission reduction credits, smog check programs, vehicle emission fees, remote sensing monitoring and tradable discharge permits. A number of programs which employ these strategies are already in place in California and should be examined before recommendations regarding the future are made. Policies aimed at dealing with new cars ultimately must address the alarming increase in the overall size of the fleet as well as provide targets or requirements for manufacturers to continually improve the emissions performance of new vehicles. We examine California’s Low Emissions Vehicle legislation as an example of such requirements.

The Gross Emitter Problem

Vehicle Retirement Programs

Emission reductions from new cars and stationary sources have grown increasingly difficult to achieve. Far easier, albeit ultimately limited, gains can be made by targeting the grossly emitting vehicles that are currently on the road through vehicle retirement programs. There are several ways to design vehicle retirement programs. A market response program would generate an incentive to reduce emissions without explicitly stating a target goal, allowing the market to control the extent to which vehicles are retired. For example, permits could be designed so that mobile source emission credits might be earned by retiring vehicles that could then be traded for stationary source emission credits. Alternatively, an emission-limiting program would directly specify emission reductions to be achieved and this goal would determine the endpoint for vehicle retirement efforts (U.S. EPA, 1993e).

M1 Program

California’s State Implementation Plan (SIP) was introduced in 1994, and described the Air Resources Board’s plans for achieving the federal one-hour ozone standards in the so called “hot spots” within California. One of these “hot spots,” the South Coast Air Basin

(SCAB) had continually failed to meet ozone standards (CARB, 1994). Therefore, alternative programs for meeting standards were explored. One of these programs, known as M1, eventually grew into what amounted to a fairly sophisticated vehicle retirement program (CARB, 1994). The M1 program was originally designed to reduce light-duty fleet emission standards for non-methane organic gases by 60% from the standard required in 2003. This was to be achieved by providing state-funded financial incentives for individuals to purchase vehicles meeting or exceeding certain ultra-low emission vehicle standards. This program encountered the extreme opposition of industry groups who had a vested interest in the petroleum based automobile market (CARB, 1998a). The Western States Petroleum Association (WSPA) and the California Chamber of Commerce proposed and lobbied for what they claimed was a better way of meeting M1 emission reduction goals. Their analysis concluded that long term vehicle retirement programs could achieve the same emission reductions originally required of the M1 proposal (CARB, 1998a).

The California Air Resources Board agreed in principle but not in terms of the required retirement projections. The WSPA predicted that only 75,000 vehicles would need to be retired between 1999 and 2010 and that 75 million dollars annually would be sufficient to meet M1 goals (CARB, 1998a). However, CARB determined that the WSPA analysis was flawed in that it did not take into account the developing California Bureau of Automotive Repairs Smog Check II Program discussed in the ensuing section. The WSPA assumed that all vehicles failing the smog check would be eligible for retirement. In reality, many of these cars will instead be brought into compliance and will remain in use. Based on this fact, revised estimates developed by CARB indicated that upwards of 150,000 vehicles would actually have to be retired in order to meet M1 emission goals. To ensure meeting these goals, CARB required that primary candidates for retirement would be vehicles that passed the last smog check, but still contributed high emissions due to a lack of advanced emission control technology (CARB, 1998a).

The M1 program is one of the first widespread programs intended to encourage the early voluntary retirement of older vehicles in order to accelerate the overall fleet turnover. The program, in its updated form, is to be implemented from 1999 to 2010 in SCAB (CARB, 1998a). Perhaps the most valuable result of the M1 debate is not the experience it has provided in terms of how to predict the number of vehicles that must be retired to achieve overall emissions reductions, but rather, the resulting suggestions as to how market forces can be incorporated into vehicle retirement programs.

Under M1, when vehicles are retired, mobile source emission reduction credits (described below) are generated for the participant funding the retirement. Mobile source emission reduction credits could then be purchased by corporations or by the State of California, which might choose to remove them from circulation. The removal of these emission reduction credits would contribute to meeting SIP targets, the original goal of the M1 program.

The Value of Mobile Source Emission Reduction Credits

The concept of emission reduction trading was first introduced in the federal Clean Air Act in 1977. Emissions trading relies on the concept of offsets. Offsets allow a new company to expand emission-producing activities only if emission reductions are achieved from another existing source, so that the net result is no new gains in overall emissions. The use of mobile source reduction credits allows flexibility for industry to meet air quality goals, a characteristic we cautiously endorse for any program aimed at improving air quality. Industry can either comply with requirements limiting emissions increases, or can obtain mobile source emission reduction credits to offset increased emissions (CARB, 1995).

While emissions trading programs help to ensure that the most cost-effective emissions reductions are undertaken, a number of pitfalls must be avoided in the program design process. First, credit should not be awarded for emission reductions that are already required by other programs, rules or laws. Furthermore the decision must be made as to whether credits should be tradable between stationary and mobile sources. There may be instances where trading vehicular emissions for stationary sources is not acceptable. If trading is allowed between stationary and mobile sources, heavy polluting stationary sources might buy up the majority of mobile emission reduction credits, potentially establishing monopoly power based upon this advantage. This might not result in maximum social or environmental benefit, even though efficiency is maximized.

Furthermore, the award of emission credit should be based on quantifiable reductions. These reductions should be permanent. For instance retired cars should be entirely scrapped. Their parts should not be allowed to extend the life of other gross emitters. Also if tradable emission credits are really meant to equate one form of emission reduction with another type of emission increase, care must be taken to ensure that the lifetime of the reduction, correlates to the lifetime of the gain (Merrifield, 1998). For instance, if a vehicle is retired which had an expected lifetime of three years, the credit generated should not ultimately allow another source to emit at the same rate for ten years.

Despite these pitfalls, we believe that the use of mobile emission reduction credits in conjunction with vehicle retirement programs provides an efficient and flexible way for meeting emissions standards.

Funding Mechanisms for Vehicle Retirement Programs

Much of the funding for vehicle retirement programs of the past has been provided in majority by government sources. For instance, CARB has instituted two fees in order to raise funds. The first is an opt-out fee that new car owners can opt to pay in lieu of their first smog check requirement, the rationale being that new cars would easily pass this first check. Second, smog impact fees are levied on out-of-state vehicles registering for the first time in California. However, neither one of these sources of funding has proved substantial enough to generate ample emission reductions under vehicle retirement programs. We believe that the involvement of industry in such programs is crucial to their ongoing support and success.

A number of methods have been proposed by which industry might provide the financial incentive to induce individuals to retire vehicles while reducing regulatory cost for themselves and generating new business. For instance, rather than pay cash for retired vehicles, as part of a regulatory requirements or in order to generate tradable emission permits through vehicular reductions, an automobile manufacturer might provide credit towards new vehicles rather than cash. This way, the manufacturer would lock in new customers while ensuring that old technology is replaced with newer cleaner technology.

In fact, the Ford Motor Company has successfully instituted just such a program in Germany, which has retired over 300,000 vehicles to date. Ford has plans to launch a similar program in southern California, targeting pre-1989 vehicles in the Los Angeles Air Basin, offering a $1000 credit towards the purchase of a new 1998 or 1999. The retired vehicles will be inspected, drained of fluids and scrapped for materials (Ford, 1999).

Private companies have also evolved whose main purpose is to facilitate vehicle retirement, acting as middlemen. Eco-Scrap, Inc. a subsidiary of Unocal, specializes in vehicle retirement and scrappage of high emitting vehicles. Eco-scrap is licensed by the South Coast Air Quality Management District (SQAMD) and has contracted with more than 120 employers providing a “turnkey “ service for the retirement of gross emitters to generate mobile emission reduction credits for contractors (Unocal, 1999).

Recommendations for Vehicle Retirement

Vehicle retirement has additional benefits, which extend beyond the obvious increase in fleet turnover time and hastening of the spread of newer and cleaner technology. Older cars are not as safe or fuel efficient as new models. There are also possible benefits from replacement lags. In the absence of vehicle retirement programs, used cars are sold and driven immediately. However with vehicle retirement programs, after retiring a car there is apt to be a lag time before the operator purchases a new car (Merrifield, 1998).

Yet, vehicle retirement programs also can have significant drawbacks, which must be considered. It is generally accepted that the polluter pays principle is the most effective way of altering environmentally damaging behavior. The close association of costs with the behavior that generates the costs, results in the transmission of proper market signals. Vehicle retirement programs however support the opposite principle, presumably for equity considerations. The car operator is rewarded for a high polluting vehicle with cash or credit towards a new car. This essentially provides an incentive for drivers to own grossly emitting vehicles. Vehicle retirement programs pose several additional problems of moral hazard, creating additional disincentives for reducing emissions-reducing behavior. Operators may choose to keep dirtier cars in service longer in anticipation of compensation from a vehicle retirement program. It is conceivable that the demand for grossly emitting cars might also increase, reflecting this ability to eventually capitalize on retirement fees (Merrifield, 1998). These are difficulties that can be overcome with proper monitoring and a carefully conceived framework.

In summary, generating support for vehicle retirement programs and fostering the role of industry in vehicle retirement programs would allow for increased efficiencies in terms of meeting emissions requirements, while decreasing the financial burden on government coffers. Perhaps even more importantly, we believe that if California is ultimately to achieve clean air, it is crucial to develop an environment in which industry participates and has a real stake. In this sense, we believe industry involvement is the ultimate factor upon which the success of retirement programs and similarly the introduction of new and cleaner technology hinge.

Hastening the Introduction of New Technology

While it is imperative to increase the retirement of gross emitting vehicles, it is also clearly crucial necessary to hasten the introduction of new technology. One effective method of doing this, which California has pursued, is the implementation of strict schedules for the emission standards of new vehicles. The previously described programs for dealing with gross emitters are, in the final analysis only short-term solutions. The efficiency and emissions technology of the fleet must increase in order to meet air quality standards.

LEV Program

In 1990, California created the Low Emission Vehicle Program (LEV) which adopted stringent emission standards in order to control emissions from light and medium duty vehicles (CARB, 1999). Under LEV regulations, vehicle emission standards are assigned according to weight classification. Seven classifications currently exist:

1. Passenger Cars: all weights
2. Light-Duty Trucks (LDT): LDT1(0-3750lbs) and LD2 (3751-5750lbs)
3. Medium Duty Vehicles (MDV): MDV2(3751-5750lbs), MDV3 (5751-8500lbs), MDV4(8501-10000lbs) and MDV5(10001-14000lbs) (CARB, 1998b)

Under LEV, several low emission vehicle standards are set within each weight classification. These standards are listed below in order of increasing stringency (CARB, 1998b):

1. Tier 1 Vehicles
2. Transitional Low Emission Vehicles (TLEVs)
3. Low Emission Vehicles (LEVs)
4. Ultra-low Emission Vehicles (ULEVs)
5. Zero-emission Vehicles (ZEVs)

Table 12 illustrates emission categories by type of vehicle and emission standards (CARB, 1998b).

Current Exhaust Mass Emission Standards for TLEV, LEV, and ULEV Passenger Cars and Light-Duty Trucks and LEV, ULEV and SULEV Medium-Duty Vehicles

Vehicle Type	Mileage for Compliance	Vehicle Emission Category	NMOG (g/mi)	Carbon Monoxide (g/mi)	Oxides of Nitrogen (g/mi)	Form-aldehyde (mg/mi)	Diesel Partic-ulate (g/mi)
All PCs; LDT1s (0-3750 lbs. LVW)	50,000	Tier 1	0.25	3.4	0.4	n/a	0.08
		TLEV	0.125	3.4	0.4	15	n/a
		LEV	0.075	3.4	0.2	15	n/a
		ULEV	0.040	1.7	0.2	8	n/a
LDT2s 3751-5750 lbs. LVW	50,000	Tier 1	0.32	4.4	0.7	n/a	0.08
		TLEV	0.160	4.4	0.7	18	n/a
		LEV	0.100	4.4	0.4	18	n/a
		ULEV	0.050	2.2	0.4	9	n/a
MDV2s 3751-5750 lbs. TW	50,000	Tier 1	0.32	4.4	0.7	18	n/a
		LEV	0.160	4.4	0.4	18	n/a
		ULEV	0.100	4.4	0.4	9	n/a
		SULEV	0.050	2.2	0.2	9	n/a
MDV3s 5751-8500 lbs. TW	50,000	Tier 1	0.39	5.0	1.1	22	n/a
		LEV	0.195	5.0	0.6	22	n/a
		ULEV	0.117	5.0	0.6	11	n/a
		SULEV	0.059	2.5	0.3	6	n/a
MDV4s 8501 -10,000 lbs. TW	50,000	Tier 1	0.46	5.5	1.3	28	n/a
		LEV	0.230	5.5	0.7	28	n/a
		ULEV	0.138	5.5	0.7	14	n/a
		SULEV	0.069	2.8	0.35	7	n/a
MDV5s 10,001-14,000 lbs. TW	50,000	Tier 1	0.60	7.0	2.0	36	n/a
		LEV	0.300	7.0	1.0	36	n/a
		ULEV	0.180	7.0	1.0	18	n/a
		SULEV	0.09	3.5	0.5	9	n/a

(CARB, 1998a; CARB, 1998b)

Table 12. Current Exhaust Mass Emission Standards

Under LEV, a separate zero emission mandate, targeting zero emission vehicles (ZEVs) was also instituted. This mandate required that major automobile makers produce at least 2% of their vehicles emission free by 1998, 5 % by 2001 and 10% by 2003. Failure to meet this quota would result in a penalty of $5000 for every ZEV not for sale. In March of 1996, California regulators eliminated the quotas described due to oil and automobile industry pressures. Still, by 2003, 10% of the new fleet would have had to meet zero emission standards under this mandate (Sperling, 1996).

LEV II

The California 1994 State Implementation Plan includes a mobile source element that calls for the adoption of technology-based emission control strategies for all light duty vehicles. These strategies aim for emissions reductions of 25 tons per day ROG plus NO_x in 2010. Under the SIP, the scheduled introduction date for this mandate is 2004 (CARB, 1998b).

The SIP also recognizes that areas with the poorest air quality may have to rely on the development of additional technology in order to improve air quality. For example, the South Coast Air Basin, would require reductions of approximately 75 tons per day ROG plus NOx to meet air quality standards. The reductions needed in addition to the proposed 25 tons per day have been classified as the “black box” (CARB, 1998b).

Proposed LEV II exhaust standards include:

	HC	**CO**	**NOx**
TLEV	.125	3.4	.4
LEV	.075	3.4	.05
ULEV	.04	1.7	.05

(CARB, 1998)

Table 13. LEVII Exhaust Standards

Requirements in the LEVII package include

1. **Lower Tailpipe Standards:**new Super Ultra Low Emission Vehicle Category (SULEV) for vehicles up to 8500lbs gross vehicle weight.
2. **Lower Fleet Average Standards:**Specific for passenger cars and the newly restructured light duty truck 2(LDT2) category
3. **Lower Particulate Matter Emissions:**Required for light-duty diesel vehicles

4. **ZEV Credits:** Partial credits for clean technologies including fuel cell vehicles and hybrid electric vehicles
5. **Zero Evaporative Standards:** Increases stringency of evaporative emission standards
6. **Smog Index Labels:** Modifications to reflect proposed standards for after 2003
7. **Hybrid Vehicle Test Procedures:** Increase effectiveness of emission measurement (CARB, 1998b)

The LEV II regulatory proposal also outlined reclassification of light-duty trucks (LDT) and medium-duty vehicles (MDV). Originally, these vehicles constituted a small portion of the fleet included trucks such as the Ford F520, used by electricians and plumbers. Vehicles such as these had a higher load capacity and were subjected to more rigorous operating conditions. Therefore, the vehicles were regulated under less stringent standards. Over the past few years however, sport utility vehicles (SUVs) and truck sales have increased dramatically. SUVs currently constitute 50% of new car sales in California (Boettcher et al., 1999). Therefore LEVII standards require that most mini vans, pickup trucks and Sport Utility Vehicles up to 8500 pounds gross vehicle weight reduce emissions to passenger car levels by 2007 (CARB, 1998b).

While these stricter standards will hasten the development and introduction of more efficient vehicle technology, we do not see reason to hesitate in making the current schedule even more rapid. Currently standards are to be adopted in 2004 and achieved by 2007. All too frequently schedules and goals for the introduction of new technology have been rolled back in the face of industry pressure. While we have stressed the importance of including industry as a stakeholder in the struggle for clean air and providing maximum flexibility, California must also hold firm to air quality goals while resisting industry’s attempts to shirk its responsibilities.

Compliance

Stringent emissions standards mean nothing unless the manufacturer guarantees them. The goal of the Compliance Assurance Program 2000 (CAP 2000) under the U.S. EPA and CARB is to redirect government and manufacturer efforts towards relying on inside the factory compliance, which would ensure that vehicles leaving the line are constructed according to stipulated emissions standards. The original CAP program emphasized:

1. Pre-production certification procedure: A manufacturer submitted test data to the Executive Officer assuring vehicle compliance prior to the actual start of production

2. Assembly Line Production Procedure: Section 2062, title 13, California Safety Code of Regulation requires emission testing of a few model vehicles prior to mass production

3. Post Production In-Use Compliance Procedure: After sale of vehicles, CARB reserved the right to procure vehicles from owners in order to test if vehicles were still in compliance.

CAP 2000 amendments provided for more flexibility while at the same time ensuring more effective compliance.

1. Amendments to pre-production procedures: This amendment significantly reduces the emission testing and reporting and allows for more flexibility for the manufacturers. Flexibility for information gathered required for certification will also be granted.

2. Amendments to Assembly Line Production Procedure: This amendment eliminates the requirement that 2% of all end of the line vehicles be tested, and assumes that continuous in factory testing is adequate

3. Implementation of Manufacturer-Conducted In-Use Testing Requirements: This amendment would require testing for vehicles at varied mileage. Specifically, testing would occur at 10,000 miles and 50,000 miles in addition to one vehicle from every test group at a minimum of 75,000, 90,000 or 105,000 miles depending on expected vehicle life.

We believe that CAP 2000 represents a balanced approach for enforcing compliance, providing simultaneously for increased industry flexibility and improved compliance. We believe that a program of this nature must be in place to guarantee that vehicles comply with current standards and that flexibility in enforcement will in turn lead to greater compliance (CARB, 1998b).

The Sport Utility Problem

The sudden increase in sport utility vehicle production and purchase warrants brief discussion. According to the Coalition for Vehicle Choice, American motorists buy more than 1.7 million SUVs per year (CVC, 1999). This accounts for over 10% of all light-duty vehicles sold annually. Because SUVs historically have been exempt from passenger car emissions standards, this trend is especially worrying. SUVs have a disproportionately large impact on total vehicular emissions.

Compact SUVs usually have 4 cylinder engines while midsize vehicles usually have 6 cylinder engines. They include such models as the Jeep Wrangler, Ford Explorer, Honda Passport and Mitsubishi Montero. Full size SUVs come with either 6 or eight cylinder engines and are often used for heavy duty towing although they are gaining popularity in the recreational market. These vehicles include the Chevrolet and GMC Suburban, Chevy Tahoe, Ford Expedition, Toyota Land Cruiser and Land Rover Range Rover. SUVs under 8500 pounds are currently subject to the federal light truck average fuel economy standard of 20.7 miles per gallon and the LEVII emission standards (CVC, 1999). However this is not enough.

Stricter emissions standards under LEV II will help alleviate the impact of SUVs in the future, but other mechanisms must be employed to affect the used sport utility vehicle market and the current market that is not yet subject to LEV II standards. Recent federal taxes on sport Utility Vehicles have been proposed in order to fund various conservation efforts. Owners of SUVs would face an excise tax of one quarter of 1% of the price of the vehicle. For example, a $25,695 vehicle would cost $64.24 more after the tax was added. We support this in principle but believe that more severe measures should probably be taken (Cole, 1998).

Unfortunately the future of the Sport-Utility Vehicle is not a clean one. Demand is still growing for SUVs and stricter emission standards on light-duty vehicles may in fact exacerbate the problem. Companies fear that more stringent LEVII regulations will cause the extinction of certain models of higher emitting SUVs such as the Chevy Tahoe and GMC Suburban. This may in fact encourage manufacturers to make even larger, less efficient and gross polluting SUVs, to avoid the new stricter standards. For instance, Ford has just announce the production of the Excursion, which is being touted as the world’s largest sport-utility vehicle. The Excursion is 3.5 tons and 19 feet long (which is nearly a foot longer than the current largest SUV, the Chevrolet/GMC Suburban). The Excursion, conceived of originally as a hauling vehicle for heavy duty commercial use, only gets12 miles to the gallon and weighs in at 8500lbs. The vehicle will comply with LEV II standards, but is not required to meet federal fuel-economy standards of 20 miles to the gallon (Associated Press, 1999).

We recommend that all passenger cars be required to follow LEV II requirements regardless of weight. We further suggest that for all passenger vehicles, fuel economy standards must be at least 20 miles per gallon. As a disincentive to the purchase of currently existing SUVS, we advocate an even larger excise tax to be assessed regularly when such vehicles are registered. Revenues from the SUV excise tax might be used as government subsidies for industry, aimed at the development of new emissions control technology.

8. Forward-Looking Policies

Future policies might draw from four options for increasing California air quality. These include switching to less polluting fuels, reducing the emissions from gasoline-powered vehicles, reducing vehicle use, or developing less polluting propulsion systems (Sperling, 1996).

We have suggested that relying on fuel formulations is not the most efficient or effective method of increasing air quality. We have also advocated reducing the emissions of the gasoline powered vehicle fleet by removing gross emitters and by introducing newer vehicles. However, we have not addressed the modification of driver behavior or the examination of less polluting propulsion systems. The purpose of this section is to recommend future research and policy options regarding driver behavior and zero emission vehicles.

Modifying Driver Behavior

A reduction in the number of cars on the road and a reduction in the number and distance of car trips would significantly improve California Air Quality. These goals may be achieved through a number of policy options including intelligent urban and suburban planning, increased public transportation opportunities through expansion of routes or more vehicles and the increase of bicycle commuter routes. In this section we suggest a specific program that might alter driving behavior while hastening the retirement of older vehicles.

Technology is currently available that allows for the measurement of direct tailpipe emissions. This technology might be combined with the use of on board sensors that would meter individual motorist behavior. These on board sensors could be accompanied by a type of credit counter. This counter would deplete emission allowances or credits that the motorists purchased. The depletion of credits might depend on both the quantity of emission produced by the driver’s vehicle as well perhaps as the quantity of emissions of other cars in the vicinity. While this technology and the requisite infrastructure are currently prohibitively expensive there is no reason to dismiss this for future consideration. This system is an effective means of targeting both driver habits and vehicle technology (Merrifield, 1998).

The case for zero-emission vehicles

Electric, hybrid or other zero-emission vehicles could significantly reduce air pollution over the next decade and could serve as a transportation system that could be mostly pollution free. The electric vehicle has a long history, yet current technological developments including the use of byproducts of both the computer revolution and the Strategic Defense Initiative during the 1980s, makes the vehicles a more feasible and economical choice for improving air quality (Sperling, 1996).

Electric vehicles are more efficient and therefore less polluting than internal-combustion engines. Motors in electric vehicles are connected to the wheels and consume no energy while the car is at rest. Braking schemes are also regenerative and can recycle half of the vehicle's kinetic energy to storage cells. Therefore electric vehicles have an advantage in stop and go traffic. Motors in electric vehicle are also significantly more efficient than motors in internal combustion vehicles. Internal combustion engines utilize less than 25% of the energy in a liter of gasoline where motors in electric vehicles convert more than 90% of the energy in storage cells to motive force. (Sperling, 1996).

Electric vehicles may also change the source distribution of emissions and other pollution. Currently, the mobile sources of emissions are from the tailpipes of vehicles. On the other hand, pollution associated with electric vehicles may be generated from a few coal or oil burning plants at distances far from urban areas where hazards are the greatest.

The infrastructure for the research and development of zero emission vehicles is already in place. As stated earlier in the report, 10% of the new fleet will have to meet the zero-emission requirement by the year 2003 (Sperling, 1996). It is clear that the use of electric vehicle technology will eventually become a reality. The question is not one of if but when and to what extent. The government should therefore provide market-based incentives to hasten this process.

The U.S. Department of Energy (DOE) Clean Cities program is a locally based, voluntary partnership of government and industry that aims to use local stakeholders in the effort to accelerate the use of alternative fuel vehicles and the creation of the necessary infrastructure (U.S. DOE, 1999). The Clean Cities program has already met with success. Approximately seventy communities across California have joined the Clean Cities Program over the past five years and approximately 240,000 alternative fuel vehicles have been deployed in both public and private fleets. As well, 4000 alternative refueling or charge stations have been established. We believe the Clean Cities Program is good example of the type of forward-looking policy required to promote government and industry cooperation aimed at the development of a viable and substantial alternative fuel vehicle market (U.S. DOE, 1999).

9. Conclusions

When examining the role of oxygenated fuel in California Air Quality, we conclude the following:

1. The use of MTBE as a gasoline oxygenate is not a preferred option for the improvement of California air quality, due to increasing water contamination, mounting public concern and growing skepticism concerning its benefits.
2. The use of oxygenates in gasoline may still be beneficial in meeting air quality goals in specific regions.
3. Future progress in reducing emissions should be achieved by improvements in vehicle technology rather than through alterations of fuel formulations, through vehicle maintenance and retirement programs, economic incentives and more rigid emission standards aimed at improving new vehicle technology.

The results of the cost benefit analysis clearly show that MTBE is a costly long-term option for improving air quality. We estimate that the use of MTBE currently costs the state of California somewhere between $1.1 and 3.1 billion dollars annually. Given the evidence that supports a growing skepticism concerning its benefits, we recommend an immediate and statewide ban on its use, in all but a few regions.

We conclude that there is a limited but specific role for oxygenates to play in state air quality strategy, and consequently advocate their continued use in a few regions. In these zones, we propose that MTBE should be phased out gradually in order to make the transition to alternative oxygenates as smooth as possible, for refiners and consumers alike. We further advocate the division of the state into three types of zones, based on the degree and nature of regional air pollution. By allowing for flexibility in how each of these zones addresses its unique air quality programs, we have established a system that, we believe, provides incentives for the local governments, refiners and consumers of the most severely polluted zones to improve their regional air quality.

We believe that significant future progress in reducing emissions will be achieved by improvements in vehicle technology rather than gasoline formulations. Thus long-term progress will be made by supporting the improvement of emission-limiting technology, while in the shorter term progress will be made by removing older cars, those responsible for a disproportionate amount of emissions. We support the continuation of vehicle maintenance and retirement programs, economic incentives and stricter emission standards aimed at improving new vehicle technology.

Despite the high costs of using MTBE, its continued ubiquitous presence in California results not from its cost-effectiveness for the state as a whole, but from the government's requirement that gasoline contain a certain amount of oxygenate. Although policy makers surely had good intentions when mandating this requirement, it has become apparent that this command-and-control measure is not in the best interests of the people of California. We conclude that MTBE is not a cost-effective option for the improvement of California air quality although the use of oxygenates in specific zones may still be beneficial in meeting air quality goals. We also conclude that future emission reduction must be achieved by vehicle technology rather than fuel formulation. We caution lawmakers against hastily embracing restrictive policies based on incomplete information, hoping to find a panacea. Rather, we urge lawmakers to establish emission goals, backed by incentives or penalties, while still allowing for flexibility in how these goals are attained.

10. References

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Appendix A

Suggested Tax Needed for Cleanup of MTBE-Contaminated Reservoirs

In calling for a ban on MTBE use in most of the state of California, we recognize that our recommendation might not be adopted and implemented immediately. Furthermore, in Type I Zones, MTBE may remain in use for six years after the eventual implementation of this policy. Therefore in light of the requisite continued use of MTBE our policy implies, we consider imposing a tax on the retail sale of gasoline that contains MTBE an effective way to internalize the cost of MTBE-contaminated water treatment.

In our cost-benefit study of gasoline formulations, we delineated the cost to treat MTBE-contaminated reservoirs as $340 to $1,480 million. Given that 13.9 billion gallons of gasoline are consumed annually in the state, we figure the proper tax in the case of statewide use of MTBE to be 2.4 to 10.6 cents per gallon.

According to a survey conducted by EPA, near 70% of Americans responded that they would be willing to pay five cents more for a gallon of gasoline that emitted less pollutants, and near 40% would accept a ten cent hike for such gasoline (Environmental News Network, 1999). In consideration of this survey, we consider the tax we estimate here to be the maximum politically feasible tax.

In the six-year transition period of MTBE-phase out after the implementation of our policies (described in section 7), this recommended tax could be imposed on MTBE-blended gasoline sold in the Type I Zones, where air quality has not attained the federal standard in terms of carbon monoxide concentration. The tax level in this case should be given as the estimated treatment cost for those reservoirs which might be potentially contaminated by MTBE, divided by the total consumption of gasoline containing MTBE. To simplify this rather impractical relationship into a useful one, we made the following assumptions:

Reservoir contamination by MTBE happens only in areas in which MTBE-containing gasoline is sold, which are Type I Zones.

The probability of an MTBE-contamination event is constant per unit volume of water supply from groundwater and surface water.

Locally specified gasoline supply completely meets the demand by local population, so that the demand and hence the consumption of MTBE-blended gasoline is proportional to the population in the Type I Zones, where MTBE-containing gasoline is sold.

Assumptions 1 and 2 enables us to estimate the reservoir treatment cost by using the statewide treatment cost multiplied by the fraction of water supply in Type I Zones of the whole state. Similarly, assumption 3) allows us to calculate the amount of MTBE-containing gasoline sold in Type I Zones areas by using the statewide gasoline consumption multiplied by the population fraction of Type I Zones relative to the state's total population. The tax level can then be calculated as the treatment cost in Type I Zones obtained through the above procedure divided by the amount of gasoline sold in these zones.

Type I Zones are composed of air basins and population data are for counties, whereas data for water supplies are given for hydrologic areas that cover considerably larger geographic areas than air basins and counties as shown in Figure A-1. The figure indicates that most of the area of the Type I Zones is overlain by the hydrologic area labeled "South Coast". Consequently, we calculated the fractions of the groundwater and surface water supplies of the South Coast hydrologic area relative to those of the whole state as shown in the Table A-1. Also we used the total population of all of the counties in the South Coast hydrologic area and calculated its fraction relative to the whole state. The fraction of groundwater supply and surface water supply are 9.4% and 5.9% respectively. On the other hand, the population fraction is 52.3%. This large population value and small water resources value significantly reduces the tax level compared with the case of statewide MTBE use and water treatment; the high estimate is 1.9 cent per gallon and the low estimate is 0.4 cents per gallon. This low estimate (0.4 ¢ per gallon) represents an almost negligible tax. The high estimate (1.9 ¢ per gallon) is also quite low in light of the survey by the EPA indicating that more than 90% of Americans would be willing to pay 3 cents more per gallon for cleaner gasoline. Therefore, we consider this tax to be politically feasible. (California Environmental Protection Agency, 1998, California Department of Water Resources, 1994, and California Department of Finance, 1998)

Figure A-1. Type I Zones, Hydrologic areas and counties

	groundwater supply (1995) (taf*[1])	fraction to whole state	groundwater treatment cost (million dollars)	
			high estimate	low estimate
South Coast hydrologic area	1,177	9.4%	$136.6	$31.6
California total	12,493	100.0%	$1,450.0	$335.0

	surface water supply (1995) (taf*[1])	fraction to whole state	surface water treatment cost (million dollars)	
			high estimate	low estimate
South Coast hydrologic area	3,839	5.9%	$1.8	$0.2
California total	65,083	100.0%	$30.0	$4.0

total water treatment cost (million dollars)	high estimate	low estimate
	$138.4	$31.8

	population*[2] (1998)	fraction to whole state	amount of gasoline sold (billion gallons)
South Coast hydrologic area	17,382,750	52.3%	7.27
California total	33,252,000	100.0%	13.9

tax for MTBE-containing gasoline (per gallon)	high estimate	low estimate
	$0.019	$0.004

*1 thousand acre-feet

*2 total of county populations of Los Angeles, Orange, San Diego and Ventura, and half of the county populations of Riverside and San Bernardino because the hydrologic area includes only a small part of these counties

Table A-1. Groundwater supply and population of hydrologic areas

Appendix A References

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Appendix B

List of reservoirs, their classification and estimated travel costs

No.	Name of Reservior	Location (County)	Boating Status	Point	Reservoir Size (AF)	Class by Size	Point	Sum of Points	Class	Estimated Travel Cost
1	Lake Almanor	Plumas	Major	3	1,143,000	Large	3	6	1	$ 16,000,000
2	Anderson Lake	Santa Clara	Usual	1	89,100	Medium	2	3	4	$ 552,694
3	Antelope Lake	Plumas	Usual	1	22,600	Small	1	2	5	$ 180,000
4	Beardsley Lake (also Hartley L.)	Tuolumne	Usual	1	97,800	Medium	2	3	4	$ 552,694
5	Lake Berryessa	Napa	Major	3	1,600,000	Large	3	6	1	$ 16,000,000
6	Bethany Forebay (also Bethany Res.)		Usual	1	4,900	Small	1	2	5	$ 180,000
7	Big Bear Lake	San Bernardino	Major	3	73,000	Medium	2	5	2	$ 5,210,844
8	Black Butte Reservoir	Glenn/Tehama	Equipped	2	143,700	Medium	2	4	3	$ 1,697,056
9	Boca Reservoir	Nevada	Usual	1	41,100	Small	1	2	5	$ 180,000
10	Bowman Lake	Nevada	Usual	1	68,500	Medium	2	3	4	$ 552,694
11	Bridgeport Reservoir	Mono	Equipped	2	42,600	Small	1	3	4	$ 552,694
12	Lake Britton	Shasta	Equipped	2	40,600	Small	1	3	4	$ 552,694
12	Bucks Lake	Plumas	Equipped	2	105,600	Medium	2	4	3	$ 1,697,056
13	(New) Bullards Bar Reservoir	Yuba	Equipped	2	966,103	Large	3	5	2	$ 5,210,844
14	Butt Valley Reservoir	Plumas	Usual	1	49,900	Small	1	2	5	$ 180,000
15	Cachuma Lake	Santa Barbara	Usual	1	190,500	Medium	2	3	4	$ 552,694
16	Camanche Reservoir	Amador/Calaveras /San Joaquin	Major	3	417,120	Medium	2	5	2	$ 5,210,844
17	Camp Far West Lake (also -- Res.)	Yuba/Placer	Usual	1	104,000	Medium	2	3	4	$ 552,694
18	Caples Lake	El Dorado	Usual	1	21,600	Small	1	2	5	$ 180,000
19	Lake Casitas	Ventura	Usual	1	254,000	Medium	2	3	4	$ 552,694
20	Castaic Lake	Los Angeles	Usual	1	323,700	Medium	2	3	4	$ 552,694
21	Cherry Lake		Usual	1	268,000	Medium	2	3	4	$ 552,694
22	Clear Lake	Lake	Major	3	313,000	Medium	2	5	2	$ 5,210,844
23	Coyote Reservoir	Santa Clara	Usual	1	22,300	Small	1	2	5	$ 180,000
24	Lake Crowley	Mono	Usual	1	183,200	Medium	2	3	4	$ 552,694
25	Cuyamaca Lake (also -Res.)	San Diego	Usual	1	12,200	Small	1	2	5	$ 180,000
26	Lake Davis	Plumas	Usual	1	84,400	Medium	2	3	4	$ 552,694
27	Lake Del Valle	Alameda	Usual	1	77,100	Medium	2	3	4	$ 552,694
28	Donner Lake	Nevada	Usual	1	9,700	Small	1	2	5	$ 180,000
29	(New) Don Pedro Reservoir	Tuolumne	Equipped	2	2,030,000	Large	3	5	2	$ 5,210,844
30	East Park Reservoir	Colusa	Usual	1	50,900	Medium	2	3	4	$ 552,694
31	Eastman Lake		Usual	1	150,000	Medium	2	3	4	$ 552,694
32	El Capitan	San Diego	Usual	1	112,800	Medium	2	3	4	$ 552,694
33	Englebright Reservoir	Nevada/Yuba	Equipped	2	70,000	Medium	2	4	3	$ 1,697,056
34	Florence Lake	Fresno	Usual	1	64,600	Medium	2	3	4	$ 552,694
35	Folsom Lake	Placer/Sacramento /El Dorado	Equipped	2	977,000	Large	3	5	2	$ 5,210,844
36	French Meadows Reservoir	Placer	Usual	1	136,400	Medium	2	3	4	$ 552,694
37	Frenchman Lake (also -- Res.)	Plumas	Equipped	2	55,477	Medium	2	4	3	$ 1,697,056
38	Grant Lake	Mono	Major	3	47,600	Small	1	4	3	$ 1,697,056
39	Lake Havasu	San	Major	3	619,400	Large	3	6	1	$ 16,000,000
40	Hell Hole Reservoir	Placer	Usual	1	207,600	Medium	2	3	4	$ 552,694
41	Lake Hemet	Riverside	Usual	1	13,500	Small	1	2	5	$ 180,000
42	Lake Hennessey	Napa	Usual	1	31,000	Small	1	2	5	$ 180,000
43	Lake Henshaw	San Diego	Usual	1	53,400	Medium	2	3	4	$ 552,694
44	Hensley Lake		Usual	1	90,000	Medium	2	3	4	$ 552,694
45	Lake Hodges	San Diego	Usual	1	33,600	Small	1	2	5	$ 180,000
46	Huntington Lake	Fresno	Usual	1	89,800	Medium	2	3	4	$ 552,694
47	Ice House Reservoir	El Dorado	Usual	1	45,960	Small	1	2	5	$ 180,000
48	Indian Valley Reservoir	Lake	Usual	1	301,000	Medium	2	3	4	$ 552,694
49	Iron Canyon Reservoir	Shasta	Usual	1	24,200	Small	1	2	5	$ 180,000
50	Lake Isabella	Kern	Equipped	2	568,000	Large	3	5	2	$ 5,210,844
51	Jackson Meadows Reservoir	Nevada/Sierra	Equipped	2	69,200	Medium	2	4	3	$ 1,697,056
52	Jenkinson Lake	El Dorado	Usual	1	41,000	Small	1	2	5	$ 180,000
53	Lake Jennings	San Diego	Usual	1	9,800	Small	1	2	5	$ 180,000
54	Lake Kaweah	Tulare	Usual	1	143,000	Medium	2	3	4	$ 552,694
55	Kerchkhoff Reservoir		Usual	1	4,247	Small	1	2	5	$ 180,000
56	Keswick Reservoir	Shasta	Usual	1	23,800	Small	1	2	5	$ 180,000
57	Lake Valley Reservoir	Placer	Usual	1	8,000	Small	1	2	5	$ 180,000
58	Lewiston Lake	Trinity	Usual	1	14,700	Small	1	2	5	$ 180,000
59	Little Grass Valley Reservoir	Plumas	Equipped	2	94,700	Medium	2	4	3	$ 1,697,056
60	Los Banos Reservoir	Merced	Usual	1	34,600	Small	1	2	5	$ 180,000

Table B-1. List of Reservoirs Used both for Water Supply and for Gasoline Powered Recreational Boating (assuming a $15 per hour wage rate).

No.	Name of Reservior	Location (County)	Boating Status	Point	Reservoir Size (AF)	Class by Size	Point	Sum of Points	Class	Estimated Travel Cost
61	Lower Bear Reservoir	Amador	Usual	1	52,025	Medium	2	3	4	$ 552,694
62	Lower Otay	San Diego	Usual	1	49,500	Small	1	2	5	$ 180,000
63	Mammoth Pool Reservoir	Madera	Usual	1	122,700	Medium	2	3	4	$ 552,694
64	McCloud Reservoir (also L. --)	Shasta	Usual	1	35,200	Small	1	2	5	$ 180,000
65	Lake McClure (also Exchequer Res.)	Mariposa	Major	3	1,024,600	Large	3	6	1	$ 16,000,000
66	Lake McSwain (also -- Res.)	Mariposa	Major	3	9,730	Small	1	4	3	$ 1,697,056
67	Lake Mendocino	Mendocino	Usual	1	122,400	Medium	2	3	4	$ 552,694
68	Millerton Lake	Madera/Fresno	Equipped	2	520,000	Large	3	5	2	$ 5,210,844
69	Lake Miramar	San Diego	Usual	1	7,200	Small	1	2	5	$ 180,000
70	Modesto Reservoir		Usual	1	29,000	Small	1	2	5	$ 180,000
71	Morena Lake (also Reservoir)	San Diego	Usual	1	50,200	Medium	2	3	4	$ 552,694
72	Murray Reservoir	San Diego	Usual	1	4,800	Small	1	2	5	$ 180,000
73	Lake Nacimiento (also -- Res.)	San Luis Obispo	Equipped	2	340,000	Medium	2	4	3	$ 1,697,056
74	Lake Natoma	Sacramento	Usual	1	9,000	Small	1	2	5	$ 180,000
75	New Hogan Lake (also -- Res.)	Calaveras	Equipped	2	317,100	Medium	2	4	3	$ 1,697,056
76	New Melones Reservoir	Calaveras/Tuolumn	Equipped	2	2,420,000	Large	3	5	2	$ 5,210,844
77	O'Neil Forebay	Merced	Usual	1	56,400	Medium	2	3	4	$ 552,694
78	Lake Oroville	Butte	Major	3	3,537,600	Large	3	6	1	$ 16,000,000
79	Pardee Reservoir (also -- L.)	Amador/Calaveras	Usual	1	197,950	Medium	2	3	4	$ 552,694
80	Perris Lake (also -- Res. & L. --)	Riverside	Equipped	2	131,500	Medium	2	4	3	$ 1,697,056
81	Lake Pillsbury	Lake	Equipped	2	80,500	Medium	2	4	3	$ 1,697,056
82	Pine Flat Dam (also Pine Flat Lake)	Fresno	Equipped	2	1,000,000	Large	3	5	2	$ 5,210,844
83	Pinecrest Lake	Tuolumne	Usual	1	18,300	Small	1	2	5	$ 180,000
84	Lake Piru (also -- L.)	Ventura	Usual	1	88,346	Medium	2	3	4	$ 552,694
85	Prosser (Creek) Reservoir	Nevada	Usual	1	29,800	Small	1	2	5	$ 180,000
86	Pyramid Lake	Los	Usual	1	171,200	Medium	2	3	4	$ 552,694
87	Redinger Lake		Usual	1	35,000	Small	1	2	5	$ 180,000
88	Rollins Reservoir (also L.)	Nevada/Placer	Equipped	2	66,000	Medium	2	4	3	$ 1,697,056
89	Ruth Lake (also -- Res.)	Trinity	Usual	1	51,800	Medium	2	3	4	$ 552,694
90	Saddlebag Lake	Mono	Usual	1	11,100	Small	1	2	5	$ 180,000
91	Salt Springs Reservoir	Amador/Calaveras	Usual	1	141,857	Medium	2	3	4	$ 552,694
92	Lake San Antonio (also -- L. & -- Res.)		Equipped	2	330,000	Medium	2	4	3	$ 1,697,056
93	San Luis Reservoir (CVP)	Merced	Usual	1	971,000	Large	3	4	3	$ 1,697,056
94	San Pablo Reservoir	Contra Costa	Usual	1	38,600	Small	1	2	5	$ 180,000
95	San Vicente Reservoir (also L.S.V.)	San Diego	Usual	1	90,200	Medium	2	3	4	$ 552,694
96	Santa Margarita Lake (also Res.)	San Luis Obispo	Usual	1	23,000	Small	1	2	5	$ 180,000
97	Scotts Flat Reservoir (also L.)	Nevada	Usual	1	48,500	Small	1	2	5	$ 180,000
98	Lake Shasta	Shasta	Major	3	4,552,000	Large	3	6	1	$ 16,000,000
99	Shaver Lake	Fresno	Usual	1	135,400	Medium	2	3	4	$ 552,694
100	Silver Lake	El Dorado/Amador	Usual	1	8,590	Small	1	2	5	$ 180,000
101	Lake Silverwood (also -- L.)	San Bernardino	Usual	1	73,000	Medium	2	3	4	$ 552,694
102	Skinner Lake (also -- Res. &L. --)	Riverside	Usual	1	44,200	Small	1	2	5	$ 180,000
103	Sly Creek Reservoir	Butte	Usual	1	65,700	Medium	2	3	4	$ 552,694
104	South Lake	Inyo	Usual	1	12,900	Small	1	2	5	$ 180,000
105	Spaulding Lake (also L. --)	Nevada	Usual	1	75,100	Medium	2	3	4	$ 552,694
106	Stampede Lake (also Res.)	Sierra	Usual	1	226,500	Medium	2	3	4	$ 552,694
107	Stony Gorge Reservoir	Glenn	Equipped	2	50,000	Medium	2	4	3	$ 1,697,056
108	Stumpy Meadows Lake (also Res.)	El Dorado	Usual	1	20,000	Small	1	2	5	$ 180,000
109	Lake Success	Tulare	Equipped	2	82,300	Medium	2	4	3	$ 1,697,056
110	Lake Tahoe	Placer/El Dorado	Major	3	732,000	Large	3	6	1	$ 16,000,000
111	Tulloch Reservoir (also -- L. & L. --)	Calaveras/Tuolumn	Usual	1	67,000	Medium	2	3	4	$ 552,694
112	Turlock Lake	Stanislaus	Usual	1	49,000	Small	1	2	5	$ 180,000
113	Union Valley Reservoir	El Dorado	Equipped	2	277,300	Medium	2	4	3	$ 1,697,056
114	Whiskeytown Lake	Shasta	Equipped	2	241,100	Medium	2	4	3	$ 1,697,056
115	Lake Wishon (also -- Res.)	Fresno	Usual	1	128,300	Medium	2	3	4	$ 552,694

Status	Sum	Average	Size	Sum	Class	Sum	Total
Major	12	276,354	Large	15	1	7	$ 226,405,642
Equipped	25		Medium	59	2	10	Average
Usual	79		Small	42	3	19	$ 1,968,745
					4	42	
					5	38	

*Major: Major Recreational Site, Equipped: Well Equipped Site, Usual: neither "Major" nor "Equipped"

*Large: more than 500,000 acre feet (AF), Medium: more than 50,000 AF but less than 500,000 AF, Small: less than 50,000 AF

Table B-2. List of Reservoirs Used both for Water Supply and for Gasoline Powered Recreational Boating (assuming a $15 per hour wage rate) (continued)