An integral cost-benefit analysis of gasoline formulations meeting California Phase II Reformulated Gasoline requirements

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Abstract

We conduct a Cost Benefit Analysis (CBA) for three gasoline formulations that meet California's Phase II Reformulated Gasoline (CaRFG2) requirements: CaRFG2 with MTBE, CaRFG2 with ethanol, and non-oxygenated CaRFG2. Cost and benefits for each formulation are compared against conventional gasoline as defined by the 1990 Federal Clean Air Act Amendments. Air quality benefits for all three formulations are essentially the same; the highest economic benefit is the reduction in benzene concentrations due to CaRFG2 specifications, which translate into reduced cancer risk for millions of people. However, CaRFG2 with MTBE and CaRFG2 with ethanol have been shown to increase emissions of aldehydes, which are also classified as potential carcinogens. Therefore, these formulations have some air quality costs associated with them. A preliminary evaluation of the most likely composition of non-oxygenated gasoline indicates that there is no additional air quality cost associated with the use of this formulation relative to conventional gasoline. In addition, oxygenated gasolines (with either MTBE or ethanol) are more expensive than non-oxygenated gasoline, which translates into hundreds of millions of dollars paid by California's consumers at the pump for these formulations.

Gasolines with MTBE have several other significant costs, associated with the release of uncombusted gasoline with MTBE to the environment and subsequent contamination of surface and groundwater reservoirs. To estimate the annual cost of treating water supplies, we consider three elements: treatment of contamination from leaking underground storage tanks, treatment of contaminated groundwater at the drinking water well, and treatment at the surface reservoir outflow. These costs are on the order of $340 million to $1.4 billion per year for California. Other significant costs include the potential loss of recreational value of California's dual-use surface water reservoirs, and the costs associated with monitoring water supplies for MTBE contamination.

Based on the results of this CBA, non-oxygenated CaRFG2 is the best option for achieving the air quality objectives, from an integral economic perspective. The value of air quality benefits is larger than the costs for non-oxygenated CaRFG2. For CaRFG2 with ethanol and CaRFG2 with MTBE, the value of costs is larger than the value of air quality benefits. The water treatment costs associated with CaRFG2 with MTBE far outweigh the value of air quality benefits, resulting in an inefficient fuel alternative, from an economic perspective.

We evaluate several policy options available to reduce the costs of the continued use of MTBE, while transitioning to non-oxygenated gasoline: (1) Restrict the use of CaRFG2 with MTBE to air quality non-attainment areas during non-attainment periods, promoting the use of non-oxygenated gasoline in all other regions, by providing refiners with flexibility in the compliance with CaRFG2 specifications, while still meeting air quality objectives; (2) Internalize the cost of MTBE-contaminated water treatment through an additional surcharge on underground storage tanks and gasoline; (3) Increase the use of ethanol as an oxygenate, by developing market incentives for promoting ethanol production in California from agricultural wastes, after a full environmental assessment of gasoline with ethanol is conducted; (4) Accelerate vehicle retirement programs to achieve air emissions reductions; and (5) Manage surface water reservoirs to reduce the levels of contamination.

1. Introduction

The previous studies in this report have explored the air quality impacts of various gasoline formulations; the toxicology of Methyl tert-Butyl Ether (MTBE), ethanol and their combustion by-products; the extent of MTBE contamination of surface and groundwaters; the likelihood of exposure to MTBE in urban air environments or through the ingestion of contaminated water; and the cost and effectiveness of various water treatment options. This study focuses on the three key questions that policy makers in California have to address with respect to MTBE when used as a gasoline additive to improve air quality:

- Have the costs of using MTBE outweighed the benefits it produces?
- What are the policy options that are available to reduce the costs of using MTBE and what are the trade-offs?
- What are the costs and benefits of alternatives to MTBE-based reformulated gasoline formulations?

Our objective in this study is to integrate the scientific, technical and economic information available on MTBE, as a result of previous studies as well as the concurrent investigations funded by SB 521, into a decision making framework that allow us to answer these questions with a reasonable degree of certainty. Accounting for the costs and benefits involves making assumptions about the probability that several events will occur (e.g., underground spills, leakage from motorized boats, damages to human health, damages to aquatic species). These probabilities have a certain degree of uncertainty associated with them. The probability can be reduced by policy decisions (e.g., ban the use of motorized boats in drinking water reservoirs) at a certain societal cost (e.g., loss of recreational opportunities). We evaluate a variety of scenarios and policies using cost-benefit analysis.

Three formulations are evaluated: (1) California Phase II Reformulated Gasoline (CaRFG2) with MTBE; (2) CaRFG2 with ethanol; or (3) Non-oxygenated CaRFG2. All of these formulations have costs and benefits associated with them, and it is not certain *a priori* which has the highest net benefit (or least cost). In addition, we evaluate the cost of policy options that can reduce the human health and environmental effects associated with using MTBE in gasoline, during the transition to other gasoline formulations.

2. Method of Analysis

Cost Benefit Analysis (CBA) is a method for evaluating proposed projects or alternatives through the systematic comparison of the value of the costs and benefits associated with each alternative. CBA has been developed as an objective tool to aid decision-makers in selecting among alternatives. It is not to be considered the final word in policy formulation, but it should be an integral part of the process. CBA is unconstrained by bureaucratic or political processes. However, these processes may influence the use of CBA results.

There are essentially two stages involved in CBA. The first stage is the valuation of costs and benefits of each alternative. The second stage is a systematic comparison of each alternative. We accomplish the first stage through the use of several valuation techniques for the following cost and benefit categories:

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

We accomplish the second stage by finding the net benefits of each alternative, that is the sum of benefits minus the sum of costs. The higher the net benefit, the better the alternative, from an economic perspective (Boardman et al., 1996).

All costs and benefits for the different reformulated gasoline formulations evaluated are estimated relative to a baseline, which is conventional gasoline (Koshland et al., 1998). For the each CBA, we assume that the gasoline formulation under study is used 100%

statewide. In reality, a combination of these alternatives is already in place in California, although for the most part refiners have chosen MTBE as the oxygenate due to incomplete economic valuation of the costs and liabilities they are incurring. This study explores those "hidden" costs and provides the information to make more complete decisions, on a micro- (individual refiner) and macroeconomic (state or nation-wide) level.

The cost-benefit analysis of fuel alternatives depicted here represents a new and useful analysis. CBA has been used to analyze the impact of several environmental regulations in the past. However, previous CBA studies that have been done in this area do not specifically focus on fuel alternatives. For example, some studies are focused on the Clean Air Act of 1970 (U.S. EPA, 1997), and offer questionable means of valuing health costs and benefits. Schwing et al. (1980) use an aggregate index of hydrocarbon emissions to compare fuels (with lead), and mistakenly attribute all health effects to carbon monoxide reductions without acknowledging lead's effects. Another study compares methanol to conventional gasoline in terms of reducing motor vehicle emissions and urban ozone, yet avoids discussing health effects altogether (Krupnick and Walls, 1992).

Table 1. Valuation Methods.

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., 1998
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

Details of the valuation calculations made for each cost and benefit are provided in Section 3 (Results) for each fuel alternative. Table 1 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. (1998), Rodriguez (1997), and Tikkanen (1998), which refer to valuation studies specifically applied to MTBE and fuel alternatives in California.

We use the cost of illness and avoidance expenditures approach for morbidity effects from water and air contaminated by each particular fuel (Abdalla et al., 1992). We use the value of a statistical life (Fisher et al., 1989) for health costs of mortality effects of direct contact with contaminated water, through ingestion or dermal contact, or the inhalation of gasoline vapors, and the exposure to products of incomplete combustion from the different gasoline types. The value of a human life estimated by Fisher et al. (1989) is adjusted to account for inflation.

Engineering estimates and market prices are used to determine water treatment costs. This information is combined with estimates on the number of sites requiring treatment, whether surface or ground water reservoirs. In cases where there is a need for alternative water supplies, these are valued through a market price of potable water from other sources.

We use market prices to estimate direct costs paid by consumers due to the mandated change to CaRFG2, which result in increased prices at the gasoline pump. For goods traded in well-functioning markets, we can usually observe the market clearing price. Engineering estimates are used to estimate the increased fuel consumption, and thus increased cost of operation, due to decreased fuel efficiency (Krupnick and Walls, 1992).

A market price approach is also used to calculate monitoring costs incurred to track the extent of contamination, in surface and ground waters, or in ambient air concentrations. We use the travel cost method to value recreational costs from possible restrictions of boats and jet-skis on bodies of water which also serve as drinking water sources. The factor income and restoration cost methods are used to value environmental health costs which account for damage to important environmental goods, such as fish and other sensitive fauna and flora (Anderson and Rockel, 1991; Bell, 1989; Shabman and Batie, 1987).

Our analysis considers the annualized costs and benefits of each alternative fuel. The analysis is a discrete time analysis and should not be viewed as a long-term continuous time analysis. Where possible, we note in our estimates situations where significant departures in the calculations may occur due to the static approach. One aspect of conducting a dynamic analysis is the use of a discount rate to account for the change in the value of money over time. There are diverse views on which discount rate is most appropriate to represent the time value of money. The reason for the diversity is due to the fact that the discount rate is rooted in preferences of individuals and it would be difficult to decide on one specific discount rate for all of society (Lyon, 1990). Another aspect of conducting a dynamic analysis involves the distinction between real and nominal dollars and discount rates. Depending on when the costs and benefits accrue, there is a monetary value stated in dollars for a particular year that needs to be adjusted for inflation and other factors that change over time. It is important to track real versus nominal costs and discount rates, and to avoid mixing estimates of real values with nominal discount rates, or viceversa. Converting our static analysis to a dynamic CBA would not prove pivotal in the overall evaluation of the fuel alternatives, since the timing of the relevant costs or benefits is similar for all three alternatives.

Conceptually, the valuation of environmental impacts of each alternative is straightforward. In practice, there are significant difficulties since important elements of the valuation process are not measured or have large uncertainties associated with them. For example, although MTBE may be associated with asthma, the epidemiological studies have not been conducted. Similarly, valuation of the effects of reducing air pollutant levels on human health once they are below the air quality standards (and thus well below available toxicological information) has a large uncertainty.

Some categories of environmental goods do not have explicit prices, and we must use indirect approaches to develop monetary equivalent values for them. For example, the costs of operating a jet ski may not include consideration of the damages it's emissions inflict on health to flora and fauna. We will use the recreational cost of using a jet ski plus the value of the environmental health damages from gas discharges to surface waters. We explain in detail the assumptions used in the valuation approaches developed throughout the study.

3. Results

The results of our CBA for each CaRFG2 formulation are presented as a matrix in Table 2. Fuel alternatives are presented in the columns, and cost or benefit categories are in the rows, including:

- air quality benefits of CaRFG2, which are essentially equal among all fuel alternatives, based on the review of Koshland et al. (1998);
- health costs associated with air quality costs of using the various oxygenates, due to the increased generation of aldehydes, which are known carcinogens;
- health costs associated with contaminated water, which include costs of averting health damages by either water treatment or using alternative water supplies;
- direct costs paid by the consumers in the form of increased prices at the pump as well as decreased fuel efficiency due to lower energy content of the oxygenates;
- other costs to the economy, including monitoring costs and recreational costs.

In some instances, the literature review and research under SB 521 indicated that the costs or benefits for a particular category were not significant, relative to the other costs and benefits we evaluated. For example, the ecological risk assessment (Werner and Hinton, 1998) indicates that the concentrations of MTBE or ethanol in the environment are typically low enough that there will be no significant damage. Of course, at the specific source of the contamination there may be some local damage, but the value of these damages is estimated to be small relative to other costs. We have indicated that these values are not significant (N.S.) in Table 2, in relative terms, although probably not zero. In all cases we present a range for the benefits or costs, given the uncertainties associated with the various elements of the valuation process. Negative costs (relative to the baseline fuel, conventional gasoline) are presented in parenthesis. A Net Benefit has a positive value while a Net Cost has a negative value.

Table 2. Annualized Cost Benefit Analysis of Fuel Alternatives.

	CaRFG2-MTBE	**CaRFG2-Ethanol**	**Non-oxy CaRFG2**
Air Quality Benefits	$2 to $66 million	$2 to $66 million	$2 to $66 million
Health Costs			
air quality damages	$0 to $27 million	$3 to $200 million	N.S.[1]
water treatment	$340 to $1480 million	N.S.[1]	$1 to$10 million
alternate water supplies	$1 to 30 million	N.S.[1]	N.S.[1]
Direct Costs			
fuel price increase	$280 to $970 million	$220 to $610 million	($280) to $280 million
fuel efficiency decrease	$310 to $400 million	$290 to $580 million	($150) to ($230) million
Other Costs			
water monitoring costs	$2 to $4 million	N.S.[1]	N.S.[1]
recreational costs	$160 to $200 million	N.S.[1]	N.S.[1]
ecosystem damages	N.S.[1]	N.S.[1]	N.S.[1]
Costs Subtotal	$1.1 to $3.1 billion	$0.5 to $1.3 billion	($0.4) to $0.06 billion
Net Benefit or (Cost)	($1.1) to ($3.0) billion	($0.5) to ($1.2) billion	$0 to $0.4 billion

[1] Not significant

Based on the CBA, non-oxygenated CaRFG2 is the best alternative to meet air quality objectives, followed by CaRFG2 with ethanol. CaRFG2 with MTBE has the highest costs, mostly due to the annual cost of water treatment, but also as a result of direct costs as well as recreational costs. The following sub-sections present the assumptions in our valuations as well as a discussion of the each cost or benefit category.

3.1 Air Quality Benefits of Reformulated Gasoline

Based on the review of the air quality impacts of RFG by Koshland et al. (1998), any CaRFG2 formulation (with MTBE, ethanol or non-oxygenated) is expected to decrease the atmospheric concentrations of two criteria pollutants, ozone and carbon monoxide, as well as two air toxics, benzene and 1,3-butadiene. Of these four pollutants, benzene has the most direct impact on human health (ATSDR, 1991; IARC, 1985). Benzene can increase the incidence of leukemias and is classified as a group A carcinogen (known human carcinogen). To estimate the economic value of the reduction of atmospheric benzene concentrations, we consider the change in benzene concentration, which when multiplied by the cancer potency or cancer risk factor provides an estimate of the potential decrease in cancer risk per million people. Multiplying this result by the most likely population exposed to benzene, we obtain the potential reduction in cancer risk for California. To translate this into a monetary value, we use an annualized value of a statistical life. The calculations are presented in Table 3.

Table 3. Economic Value of Changes in Atmospheric Concentrations.(Values in 1998 dollars)

	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

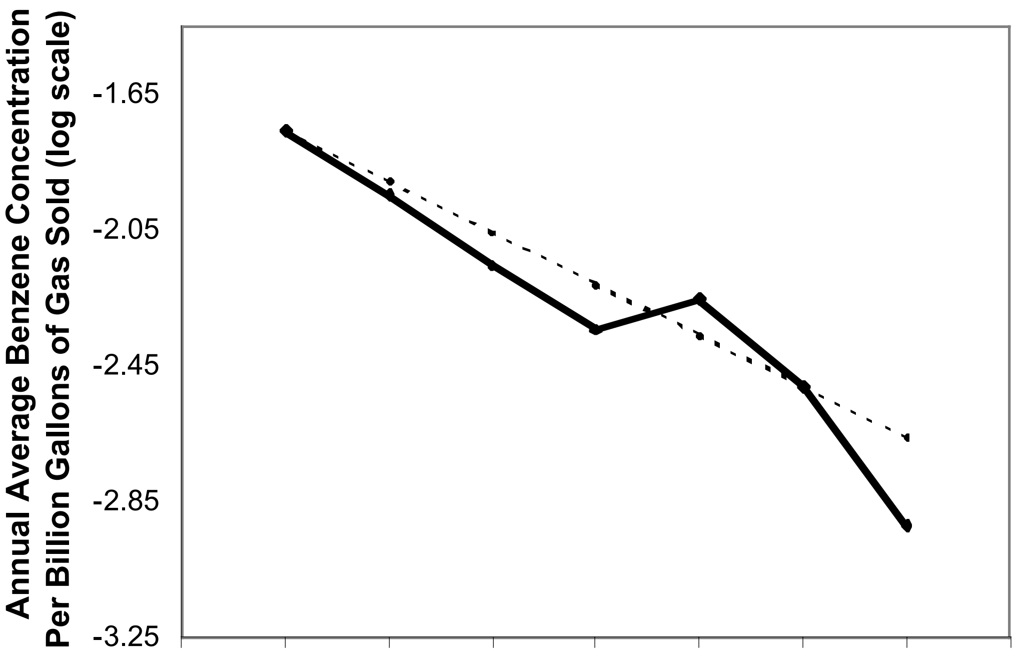
The range in cancer potency has been established by a scientific review panel (CAL-EPA, 1997). Cancer potency expresses the per capita risk of contracting cancer based upon ambient concentrations of the pollutant. These values are given in terms of per capita risk per ug/m^3 of pollutant; we convert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

Figure 1. Annual average benzene concentration in California.

(Per billion gallons of gasoline sold, log scale)



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 a average lifetime used to calculate the cancer potency (70 years) to yield the annual dollar value of the benefit of reducing benzene concentrations.

1,3-butadiene is a carcinogen in laboratory animals and is classified as a B2 carcinogen (probable human carcinogen) (USEPA, 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.

3.2 Air Quality Costs

3.2.1 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) (USEPA, 1993c, 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.

3.2.2 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. USEPA has designated acetaldehyde as a B2 probable human carcinogen (USEPA, 1993b, 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 under exercise. 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.

3.2.3 Non-Oxygenated CaRFG2

To produce non-oxygenated CaRFG2, the most likely replacement of MTBE is toluene. One immediate concern is the potential increase in toluene concentrations. Toluene can be neurotoxic at high concentrations (ATDSR, 1992). According to the USEPA, toluene has a Reference Concentration (RfC) in air of 0.4 mg/m^3 or 400 ug/m^3 (USEPA, 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.

3.3 Direct costs of fuel price increase and decline in fuel efficiency

3.3.1 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 the number of months during which oxygenation was required and specifically which months. 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 are not market reality.

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 both approaches in order to establish a range of costs.

Table 4. Average Retail Prices of Conventional Gasoline and RFG[1]

(data in cents per gallon)

	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, Motor Gasoline Price Survey, Form EIA-878

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

3.3.1.1 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 4 presents the available data.

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.

3.3.1.2 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 5). 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.

Table 5. Average 1996 Wholesale Prices of Conventional Gasoline & RFG[1]

(data in cents per gallon)

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

[1]Source: U.S. Department of Energy, Petroleum Marketing Annual 1997 Tables 32, 34

3.3.1.3 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* (1998). Similarly, we calculated a three-year national average price for wholesale gasoline of (unoxygenated) of 72 cents per gallon using Platt's Petrochemical Service *Motor Fuels Data* (1998). 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.

3.3.1.4 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, 1995). Also, cost impacts depend on the types of crude oil the refinery can run 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." 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.

3.3.1.5 MTBE Fuel Efficiency Considerations

Fuel economy 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 fuel efficiency 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 fuel efficiency 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 Californian consumers due to maintenance or engine performance.

3.3.1.6 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.

3.3.2 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.

3.3.2.1 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 boarder (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.

3.3.2.2 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.

3.3.2.3 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 whose oxygen content is 3.5 %. Consequently, under any scenario whereby producers were compelled to use ethanol, it is likely that they might chose 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 fuel efficiency 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 a 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.

3.3.2.4 Fuel Efficiency

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 fuel efficiency of RFG is moderated by the fact that oxygenation at the 2 % level requires less ethanol than MTBE (5.7% versus 11%). Reductions in fuel efficiency of up to 3% relative to non-oxygenated fuel have been estimated (NSTC, 1997). Clearly if fuel efficiency 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 fuel efficiency 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 fuel efficiency 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.

3.3.2.5 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.

3.3.3 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. 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, 1998). 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.

3.4 Cost of Water Treatment

3.4.1 Groundwater Contamination

The major source of groundwater contamination is the failure of fuel storage tanks, in particular Underground Storage Tanks (USTs). Pipeline failures are the second most important source of contamination. Gasoline with MTBE flows down towards the aquifer where it eventually pools. MTBE dissolves preferentially given its high solubility (NSTC, 1997). Since MTBE does not sorb significantly to aquifer materials and is degraded only very slowly under natural conditions (Squillace et al., 1996), it can form very long plumes that are much more likely to reach wells used for drinking supply. Studies by Happel et al. (1998) and Fogg et al. (1998), indicate that the probability of contaminating a larger volume of water is much higher for MTBE than other gasoline components, including benzene, toluene, ethylbenzene and xylenes (collectively called BTEX).

Although there are no established clean-up goals for MTBE contamination, the risk-based analysis conducted by CAL-EPA (1998) and the more restrictive taste and odor concerns are the likely drivers for treating MTBE contamination. From the preliminary Public Health Goal (PHG) recommended by OEHHA (CAL-EPA, 1998), it is likely that a primary Maximum Contaminant Level (MCL) of 14 ug/L will be set as a response to the Local Drinking Water Protection Act of 1997 (22 CCR Section 64450). From a practical perspective, the secondary MCL of 5 ug/L, based on taste and odor, is likely to become the *de facto* action level and treatment standard for MTBE-contaminated water. These treatment levels will likely apply to water extracted from the aquifer, either for drinking water supply or for the containment and remediation of a site. Specific soil clean-up goals will be set by the Regional Water Quality Boards, most likely based on the projected risk of contaminating groundwater supply.

To estimate the cost of groundwater treatment in California, the following information is required:

1. Unit cost to characterize a site, to develop a feasibility and remediation study, and to implement extraction and monitoring wells, as well as general site management costs. Given the large variability in site characteristics, a range of unit costs is required.
2. Unit cost of water treatment, using most cost-effective technology, at a range of flowrates and concentration levels that are most likely to be encountered. This information is available from the MTBE Research Partnership (1998) study and from the study being conducted by Keller et al. (1998) as part of SB 521.
3. Number of sites that require treatment. This information must be projected over time, estimating the number of storage tanks and pipelines that are likely to fail and leak in the future. An estimate of typical site MTBE concentration, amount of fuel released and overall dimensions of contaminated site is required.
4. An estimate on the time required to remediate a site, which depends on regulatory and economic factors.

3.4.1.1 Site Characterization Costs

Important site characteristics that affect the cost of site investigation are subsurface geology, size of MTBE source, depth to groundwater, recharge of the aquifer through infiltrated precipitation, time since the initial leak, and local and regional hydrogeology. These parameters affect the extent of horizontal plume travel as well as the vertical movement of the plume. Dooher (1998) has evaluated site characteristics for over one thousand contaminated sites to develop a typical profile for California. While this may be used to make generalized cost estimates, each site has its own characteristics and must be evaluated on a case-by-case basis.

Generalized estimates for site investigation costs were obtained from several industry representatives. These costs ranged from $30,000 to $250,000 for typical gasoline station sites, with plume lengths ranging from 20 to 1000 feet. A few sites have a complex hydrogeological environment or large gasoline/MTBE source zones that can result in longer or deeper plumes, increasing the costs of site investigation up to $2.5 million. Since MTBE is more mobile and less degradable than any other gasoline component, MTBE plumes will typically be 50 to 100% more expensive to characterize than comparable plumes from conventional gasoline with no MTBE. During the investigative process sites are often prepared for remediation by placing monitoring and potential extraction wells, reducing the remediation costs.

3.4.1.2 Soil Remediation Costs

A typical gas station contaminated site requires 24 to 60 months to remediate, if soil and water treatment are done concurrently, with an average of 36 months for remediation. These estimates are based on typical BTEX plumes or on BTEX plus MTBE plumes, where the MTBE has not migrated very far. Since MTBE plumes are bigger and getting still bigger, remediation times may be substantially larger if action is delayed. Although there are several studies underway to determine the possibility of in-situ treatment, including bioremediation, these technologies have not yet been proven. Therefore, we consider a pump-and-treat strategy to contain the plume and remediate the soil. Soil treatment will be required for the site regardless of the type of gasoline used. No additional costs of soil treatment are expected for sites with MTBE relative to sites with conventional gasoline components. The typical cost of soil remediation, assuming Soil Vapor Extraction (SVE) with treatment of the extracted vapors using either an Internal Combustion Engine, Activated Carbon or Thermal Oxidizers, is on the order of $3,000 to $6,000 per month, per site, with an average value of $4,500 per month per site (Archabal et al., 1997a,b). This considers the cost of renting the SVE equipment as well as the operating costs (labor, materials, fuel or electricity, equipment maintenance, sampling and analytical costs, administrative costs). Soil remediation is typically done in the first part of the site clean-up, with an average time of 18 months and a range from 6 to 36 months. A 20% contingency is considered in our estimates. Based on these estimates, the typical gas station site costs $97,000 for soil treatment, with a range in costs from $22,000 to $260,000. The soil remediation cost is not very sensitive to whether the gasoline contained MTBE or not.

3.4.1.3 Groundwater Treatment Costs

Water treatment for leaking tank sites is required if there is a significant risk of human exposure. Typical pumping rates for these sites range from 10 gal/min to 100 gal/min. The rate depends on several technical and economic factors. For example, to capture an MTBE plume which has extended significantly, a higher pumping rate (in an individual well or in a number of wells) is required. However, the porosity and hydraulic conductivity of the soil and water drawdown limitations may determine the maximum flowrate allowable for a particular site. Assuming the pumping is done continuously throughout the remediation time, the total volume of water pumped may range from 10 million to 260 million gallons, with an average of 80 million gallons treated. In a pump-and-treat strategy, the volume of water that must be treated is many times more than the volume of contaminated water, since the capture zone must extend beyond the limits of the plume. In addition, until the source of the contamination is removed via SVE, fresh water is continuously contaminated as it passes through the source zone.

A cost and performance evaluation of five different water treatment technologies at various flow rates and concentrations (Keller et al., 1998) indicates that liquid-phase biofiltration is the lowest cost technology at flowrates of 100 gal/min and greater (Table 6). Air stripping is the second lowest cost technology for high flowrates, if no air treatment is required. Hollow fiber membranes are the lowest cost treatment for flowrates of 10 gal/min if no air treatment is required, which is typical at these low flowrates. GAC will be the most cost-effective technology for flowrates on the order of 10 gal/min if air treatment is required. AOP is in all cases more expensive than the alternative technologies, and there are sufficient uncertainties at this point with respect to by-products of AOP to warrant further study of this technology before it can be applied in the field. It has the potential of being cost-competitive at high flowrates, provided it is fully tested at the field scale. The cost of treating MTBE-contaminated water is 40% to 80% higher than treating water contaminated only with other hydrocarbons such as benzene, for conventional technologies such as air stripping and GAC.

Table 6. Amortized Cost, Dollars per 1000 gallons treated

Case	1	2*	3*	4*	5	6	7*	8*	9*	10*
Concentration (ug/L)	100	100	100	500	1000	5000	100	500	1000	5000
Flowrate (gal/min)	1000	500	100	100	100	100	10	10	10	10
Air Stripping										
MTBE (no air treatment)	0.23	0.25	0.40	0.59	0.68	0.88	1.54	2.30	2.65	3.55
MTBE (with air treatment)	0.33	0.41	0.76	0.84	0.88	0.97	2.35	2.68	2.84	3.22
GAC										
MTBE w/low organics	0.34	0.38	0.55	0.81	0.98	1.67	1.20	1.81	2.24	3.85
MTBE w/high organics	0.39	0.44	0.61	0.93	1.15	2.05	1.32	2.09	2.62	4.71
AOP										
Ozone/Hydrogen Peroxide	0.29	0.41	1.17	1.52	1.68	3.48	3.55	4.19	4.19	5.78
UV/Hydrogen Peroxide	0.62	0.65	1.30	1.35	1.40	1.83	3.15	3.20	4.01	4.06
Liquid Biofiltration										
MTBE	0.13	0.21	0.53	0.53	0.53	0.84	3.40	3.40	3.40	3.96
Hollow Fiber Membrane										
MTBE (no air treatment)	0.69	0.72	0.78	0.78	1.16	1.16	1.05	1.05	1.46	1.46
MTBE (with air treatment)	1.05	1.12	1.35	1.66	2.25	3.05	1.91	2.29	2.96	3.96

*air treatment may not be required for this system.
N.A. = not applicable, since benzene cannot dissolve to this concentration.

According to Happel et al. (1998), the typical Leaking Underground Fuel Tank (LUFT) site has an MTBE concentration of 200 ug/L, with a range from 5 to 10,000 ug/L. For contamination near the source zone, the concentrations are high (100 to 5000 ug/L) and the typical pumping rate is from 10 to 100 gal/min. Including a 20% contingency, the water treatment costs would range from $140,000 to $240,000, with a typical value of $190,000. The cost of a similar BTEX only site, treated to the 1 ug/L standard, would be approximately $55,000 to $180,000, with an average cost of $110,000 for water treatment. Table 7 presents the estimated overall cost of groundwater remediation for typical gasoline sites. Since the expenditures occur overall several years, the costs are also expressed in terms of an annualized cost, based on the expected time required for site remediation.

Not all sites will require soil remediation and groundwater treatment. Based on the report by Lawrence Livermore National Laboratory (Rice et al., 1995), 80 to 90% of conventional gasoline contaminated sites may be dealt with the natural processes of dispersion and intrinsic biodegradation, also called natural attenuation. Since these natural processes have to be monitored, there are additional costs to site investigation, which may range from $25,000 to $50,000 per site. Therefore, the large majority of conventional gasoline (or non-oxygenated gasoline) sites will cost around $48,000 to $240,000, considering natural attenuation. Sites that are close to drinking water supplies must be completely remediated. Since MTBE does not significantly biodegrade in groundwater systems, MTBE plumes will continue to extend and are more likely to impact a larger volume of groundwater and/or a drinking water well. Therefore, active remediation is preferred in most MTBE cases.

Table 7. Total Groundwater Site Remediation

	Gasoline with MTBE		Conventional Gasoline	
	Range	Typical	Range	Typical
Site investigation	$30,000 - 250,000	$100,000	$20,000-170,000	$77,000
Soil Remediation	$22,000 -260,000	$97,000	$22,000-260,000	$97,000
Water treatment	$140,000-240,000	$190,000	$55,000-180,000	$110,000
Total	$190,000-750,000	$390,000	$97,000-610,000	$280,000
Annualized Cost	$95,000-150,000	$130,000	$50,000-120,000	$93,000

Pipeline ruptures typically involve significant larger volumes of gasoline released than gas stations, since large flowrates of gasoline are being pumped through the pipeline and by the time a leak is detected a significant volume of gasoline may be released. For example, a recent leak in the Sierra Pacific Partners Pipeline in the Placer County region resulted in the release of at least 12,000 gallons of fuel before the leak was stopped. Although the cost items are similar, one can expect that the cost of remediating a pipeline rupture will be in the high end of our previous calculations, with a soil treatment cost of around $250,000 and a water treatment cost of $250,000. Other costs may be incurred in the case of pipeline ruptures, where the gasoline components may affect water distribution PVC pipes, as in the case of the Placer County pipeline rupture. Including site investigation costs, clean-up of a typical pipeline spill may cost from $500,000 to $1,000,000 per event.

3.4.2 Aggregate Cost of Water Treatment in California

The annualized cost of treating MTBE-contaminated surface and ground waters in California is estimated to be on the order of $340 to $1,480 million, relative to the cost that would have incurred if conventional gasoline had been used. The major treatment cost is the clean-up of Underground Storage Tank (UST) leaks, which is expected to cost from $330 to $1,400 million above the cost that would have been incurred if conventional gasoline without MTBE had been used. The groundwater remediation cost includes the legacy of older leaking USTs that stored gasoline with MTBE, which will cost from $320 to $1,030 million per year to remediate, relative to conventional gasoline leaks. The projected cost of future leaks of MTBE from upgraded USTs is between $7 million and $370 million, relative to conventional gasoline.

Based on the information from Fogg et al. (1998), there are an estimated 350 active UST sites in California that have not been upgraded and are likely to have MTBE at levels which will impact groundwater. There are an estimated 3,270 groundwater sites with detectable levels of MTBE, that have not yet been remediated, and it is likely that 2,100 of these sites (64%) will have MTBE concentrations greater than 100 ug/L. These sites represent the remediation backlog of the use of MTBE and the older UST technology that must be remediated in the next few years.

In addition, there are approximately 54,500 active tanks used for petroleum products (including gasoline, diesel, jet fuel, fuel oil, solvents, etc.), and an estimated 75-80% of these contain gasoline, or 41,000 to 44,000 tanks (EPA Office of Underground Storage Tanks, 1998). The annual failure rate for older tanks is around 2.7%, but the failure rate for upgraded tanks is estimated to be lower (Couch and Young, 1998), in the range from 0.07 to 2% per year, resulting in 30 to 880 new UST failures per year. The large uncertainty in this estimate reflects the unknown performance of upgraded USTs. If the technological improvements in leak prevention, detection and monitoring prove successful, the future number and size of gasoline leaks, leaks from these systems could result in very low annual costs, reducing the cost of using MTBE; the high estimate is based on current failure rates of underground tanks.

To estimate the aggregate annualized cost of water treatment, we compare the treatment of MTBE contaminated sites versus the same number of sites if conventional gasoline had still been used. The difference is important since approximately 80% of conventional gasoline leaks are dealt with natural attenuation, whereas we estimate that only 10% of MTBE/gasoline leaks can be naturally attenuated. Table 8 summarizes the calculations.

Table 8. Aggregate Annualized Cost of UST Treatment

		Gasoline with MTBE		Conventional Gasoline	
	Number of sites	90% full remediation	10% natural attenuation	20% full remediation	80% natural attenuation
Older active USTs	350	$60 to 240 million	$2 to 11 million	$7 to 44 million	$13 to 70 million
Older UST sites	2100	$360 to 1,420 million	$40 to 160 million	$42 to 270 million	$81 to 420 million
Subtotal	2450	$420 to 1,660 million	$42 to 170 million	$49 to 310 million	$94 to 490 million
Annual upgraded tank failures	30-880	$15 to 590 million	$2 to 68 million	$2 to 110 million	$8 to 180 million

Pipeline failures also represent an important water treatment cost. Based on information from the Office of the California State Fire Marshall (CSFM), there are 30 to 35 leaks per year in the 7,400 miles of pipeline they monitor. There are an estimated 250,000 to 300,000 miles of pipeline in California, of which 45% are used to handle refined petroleum-based products. Assuming that 70% of the refined product is gasoline with MTBE, there are approximately 79,000 to 95,000 miles of pipeline that transport gasoline with MTBE. Many of these pipelines pass through private property and are thus not monitored by CSFM. If the failure rate is similar for the larger network, then there are an estimated 370 to 450 pipeline failures that release MTBE into the environment per year. A conservative estimate of the number of releases that impact groundwater would be on the order of 100 to 150 events per year, at an annualized cost of $15 million to $38 million. If only conventional gasoline was in use, the cost would be approximately 25 to 30% less, or $10.5 million to $28 million per year.

Treatment of contaminated public and private drinking water wells is estimated considering 60 to 340 contaminated public wells and 1200 to 2000 contaminated private wells (Fogg et al., 1998). For the unit treatment cost estimates, the high flow rate/low concentration (100 ug/L) scenarios developed by Keller et al. (1998) are considered (Cases 1, 2, 3 and 7 in Table 6). The public wells pump an estimated 3 to 90 billion gallons of water per year, with an average annualized treatment cost of $1.8 million to $36 million. The private wells pump an estimated 0.6 to 2 billion gallons per year, with an average annualized treatment cost of $1.2 million to $4 million.

Treatment of contaminated drinking water from surface water reservoirs is estimated to cost $4 to $30 million. We base our estimate on the number of lakes and reservoirs that can be contaminated since they are also used for recreational boating (Reuter et al., 1998), and an estimate of water supplied by these reservoirs. There is significant uncertainty on the number surface water reservoirs will become contaminated above the 5 ug/L level, and whether through management of the reservoir by the water suppliers can reduce or eliminate the treatment costs. In addition, many public water utilities have both surface and groundwater sources, and it is possible that the balance between sources would shift depending on levels of contaminated in each type of source.

The annualized cost of treating water supplies contaminated with MTBE, relative to the cost that would have been incurred if conventional gasoline with no MTBE had been used, is summarized in Table 9. Given the uncertainty in the estimates, the values are rounded to reflect at most two significant figures.

Table 9. Aggregate Annualized Cost of Water Treatment[1]

	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

A literature review indicates that the cost of using ethanol, in terms of risk to the water supplies, is low. Ethanol plumes biodegrade fairly rapidly. Undocumented studies indicate that if ethanol and BTEX are present, the intrinsic microbial population will preferentially degrade ethanol rather then BTEX, potentially extending the length of the BTEX plume. Further studies are required to determine if this is a significant concern. In the event that water supplies become contaminated with ethanol, the available toxicological information does not support treating the water to the low levels required by MTBE, and filtration in biologically active GAC would probably be a cost-effective option. We consider the incremental costs of water treatment to be negligible relative to conventional gasoline, since BTEX compounds in the gasoline fraction would determine the treatment design, rather than ethanol.

For non-oxygenated gasoline, the differential cost of remediation and/or water treatment relative to conventional gasoline is small. The increased volumetric fraction of toluene in non-oxygenated CaRFG2 will result in higher initial toluene concentrations, but toluene is easily biodegraded by the intrinsic microbial communities. It is likely that natural attenuation will be applicable at the same rates as for conventional gasoline. Above-ground treatment costs may increase at most 10% relative to treating water contaminated by conventional gasoline. Using the calculations in Table 8, this could represent an annualized cost increase of $600,000 to $10 million relative to conventional gasoline. This is based on the failure of 30 to 880 USTs per year, and considering that site investigation and soil remediation costs are the same as for conventional gasoline; the only difference is the incremental cost of above-ground water treatment.

3.4.3 Costs of Alternate Water Supply

Some utilities are faced with using an alternate water supply, at least in the short term (e.g., the city of Santa Monica). To estimate the cost of alternate water supply, we use as our basis the $440 per acre-foot or $1.65/1000 gallons that Santa Monica pays for water from the Metropolitan Water District (Rodriguez, 1997). Based on the number of groundwater supplies that are likely to be contaminated, we estimate the cost of replacing 20 % of the potential 3 to 90 billion gallons of contaminated water per year. The total cost per year for alternate water supply would be $1 million to $30 million. We assume that this is a temporary measure for most utilities, since the cost of water treatment would be lower than alternate water supply. In addition, if many utilities took this route, the cost of alternate water would likely increase, making it much more attractive to opt for a treatment system.

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

3.5 Water Monitoring Costs

Estimates for the statewide annual monitoring costs for surface waters are drawn from recorded monitoring costs at the East Bay Municipal Utilities District reservoirs (Tikkanen, 1998). For most surface water reservoirs, these costs will be on the order of $10,000 to $25,000 per year, per reservoir. They are based on the number of sample taken per month (typically 10 per reservoir, with significant variability in the number of samples), the analytical cost (ranging from $50 to $100 per sample), and the cost of collection, which includes labor and boating expenses ($500 to $800 per month). There are 765 surface water reservoirs used for drinking water, but based on Assembly Bill 2439, we estimate that reservoirs also used for recreational boating are around 100 to 150 reservoirs. Experience has shown that specific monitoring for MTBE is done only in those drinking water reservoirs which have recreational boating use. Hence, the annual monitoring expenses for surface water reservoirs may eventually total $1 million to $4 million.

Monitoring of groundwater sources for MTBE occurs as part of the regular monitoring of any UST, whether it contains gasoline with MTBE or any other regulated chemical. We don't consider additional costs to the economy from monitoring these USTs. Cost of monitoring MTBE spills is considered in section 3.4. Drinking water suppliers that use groundwater sources may increase the frequency of their Volatile Organic Compounds monitoring as long as MTBE is used. According to CAL-DHS information (1998), there are 3,756 drinking water source wells. Each of these wells may be sampled annually rather than every three years, as required by CAL-DHS regulations. This could result in an increased annual cost of around $1 and $2 million.

Monitoring air quality is done by collecting samples on a regular basis and running a standardized analysis, which provides information on a number of air toxics. We do not consider any additional costs will be incurred to monitor ambient air concentrations of MTBE, formaldehyde, acetaldehyde, benzene or combustion by-products.

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

3.6 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 includes the cost 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 and thus we can assume that it depends only on the characteristics of the lake. Based on this assumption, we classify 115 reservoirs used for both recreational gasoline powered boating and water supply into several groups (See Table 14 in the Appendix 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 the Table 10.

Table 10. Classification of Dual-Use Reservoirs and Lakes

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

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 fees 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, then we obtain the total price of gasoline that is used for boating through following calculation:

Total gasoline cost 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 two 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 [2 people] x [0.25 hours] x [$15 per hour]
+ [4,391 x 0.10 cars] x [2 people] x [2 hours] x [$15 per hour]
= $29,639 + $26,346 = $55,985

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

Total travel cost

= Fee + Gasoline price for boat + Driving cost + Time cost
= $150,762

The total travel cost per year for the Calero Reservoir is estimated at $150,762 for the $15 per hour wage rate and $188,084 for $25 per hour wage rate. Therefore, the travel cost for reservoirs of class 5 is approximately $150,000 at the $15 wage rate. Using the following equation, we estimate the total travel cost for different classes (Dickey, 1975):

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

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

Using the Calero Reservoir information, R has a value of 4. Based on the information for Calero Reservoir and from Lake Tahoe (class 1), we estimate the total travel cost for each class, as shown in Table 11. The two reservoirs place a lower and upper bound on our estimate.

The state-wide estimate of the total travel cost for the recreational gasoline-powered boating is approximately $160 to $200 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.

Table 11. Total Travel Cost per Reservoir and Class

(assuming a $15 per hour wage rate)

Classes	Travel Cost for each reservoir	Number of reservoirs	Total travel cost for each class
1	$10,600,000	7	$74,200,000
2	$3,656,000	10	$36,560,000
3	$1,261,000	19	$23,959,000
4	$435,000	42	$18,270,000
5	$150,000	38	$5,700,000
Total		115	$158,680,000

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

3.7 Ecosystem Damages

Based on the ecological risk assessment by Werner and Hinton (1998), there are no expected damages to biota in aquatic ecosystem at the concentrations of MTBE that have been detected in lakes and water reservoirs. Localized spills may have an impact, but there is insufficient data to estimate the ecosystem damages, and they are likely to be small relative to other MTBE costs. Note that all damages and costs are estimated relative to the use of conventional gasoline. For example, local ecosystem damages due to a pipeline rupture would be very similar whether the gasoline contained MTBE or not.

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

4. Discussion of the Results of the Cost-Benefit Analysis

The net benefits of each column are derived by subtracting the total costs from total benefits. The net benefits for non-oxygenated CaRFG2 of $0- $0.4 billion rank this fuel first among the three fuel alternatives. The other two fuels have net costs. CaRFG2-Ethanol, has the lower net costs of $0.5 - $1.3 billion. Finally, CaRFG2-MTBE has the largest net costs of $1.1 - $3.1 billion, which would rank it last out of the three fuel alternatives.

We realize that some of the costs for CaRFG-MTBE overlap and therefore, the net costs represent an upper bound. For example, if water treatment costs are incurred to clean up water supply, the costs for alternative water supply will not incurred, except for the immediate supply of water prior to treatment being completed. Additionally, the costs for water treatment would not be as high if the costs of banning all recreational motorized boating are taken into account and the surface water reservoirs are no longer contaminated by MTBE discharges from boats. Adequate monitoring of MTBE levels in surface water reservoirs will initiate boating restrictions that reduce the potential cost of water treatment. Careful monitoring of USTs will reduce the future releases of MTBE and thus reduce the cost of groundwater treatment.

We list ranges for values instead of point estimates for most of the benefit and cost categories. Doing so enables some means of acknowledging uncertainty. For example, the category of costs for water treatment has a range due to the unknown number of leaking underground storage tanks. The range used reflects some attempt at forecasting failure rates of tanks. Our assumption has been that the cost of MTBE began in June 1996. Therefore we consider the cost of leaking underground storage tanks that need to be remediated from that date on. One could also look only at the failure of currently active tanks (most of which are upgraded). Another example is the large range in air quality benefits and costs, which is driven by the uncertainty in the cancer potencies of the various air toxics. The ranking of the fuel alternatives does not change based on the use of the ranges.

5. Policy Options

The CBA thus far assumes one fuel formulation is used 100% throughout the state. If MTBE continues to be sold in California, there are a number of policy options that can be implemented to reduce the risks and costs associated with the meeting the current Federal RFG and CaRFG2 requirements. We studied five policy options, which relax the assumption that only one fuel formulation is used statewide. These policies are not mutually exclusive, and may be implemented in various combinations.

Policy 1. Restrict the use of CaRFG2 with MTBE to non-attainment areas during non-attainment periods, promoting the use of non-oxygenated gasoline in all other regions, by providing refiners with flexibility in the compliance with CaRFG2 specifications, while still meeting air quality objectives

Based on improvements in air quality throughout California, US EPA officially re-designated only the South Coast Air Basin (SCAB) as a CO Federal non-attainment area on March 31, 1998. CARB also evaluated CO non-attainment areas, based on State criteria, and retained SCAB, Calexico, Fresno and El Dorado. Fresno and El Dorado may soon be re-designated as CO attainment areas. Ozone non-attainment areas were also revised, such that in terms of Federal requirements only SCAB, Sacramento and San Diego counties are still in non-attainment. CARB has recently re-designated the following urban air basins as non-attainment areas for ozone: LA, Orange, Riverside, Ventura, San Bernardino, Imperial, San Diego and Sacramento counties.

These areas have a total population of approximately 21 million people, out of a total 33 million in the state. They consume approximately 60-65% of the gasoline sold in California or 8 to 9 billion gallons per year. If in addition oxygenated gasoline is restricted to "non-attainment" seasons, the total amount of oxygenated gasoline required would be 5 to 6 billion gallons per year. The price differential between oxygenated and non-oxygenated CaRFG2 alone would result in savings to California's consumers of $100 to $300 million per year. In addition, eliminating the source of MTBE in large parts of the state would reduce future expenditures to treat contaminated water.

Policy 2. Internalize the cost of MTBE-contaminated water treatment through a surcharge (tax) on underground storage tanks and gasoline.

The taxes are suggested in conjunction with the existing Underground Storage Tank Cleanup Fund Program (USTCF) for the State of California to maintain and possibly augment the USTCF beyond the year 2005. Currently, UST owners pay an annual fee as part of the financial responsibility compliance requirements through 40 CFR 280 Federal laws pertaining to underground storage tanks. The USTCF provides insurance to tank owners. The USTCF also provides financial assistance for eligible cleanup costs and damages awarded to third parties injured by leaks and spills. In addition to reimbursing claimants for corrective action costs, the Fund provides money to the Regional Water Quality Control Boards and local regulatory agencies to abate emergency situations or clean up sites which are posing a threat to human health, safety, and the environment (SWRCB, 1997). Tank owners are scheduled to stop paying the annual fee by 2005.

Thus far, the fund generates $90,720,000 million annually through a fee of $0.012 per gallon storage for each owner. As an example of how the annual revenue amount is arrived at, a typical tank has a throughput of 10,000 gallons per month, for 12 months a year, which amounts to $1440 per tank per year. Since there are approximately 63,000 tanks in the state of California, the revenues generated from the payments total $90,720,000. As of September 30, 1997, the USTCF had collected $717 million from fees and interest earned on the fees. The total of expended and committed funds to cover claims was $635 million. Therefore, by 1997 the USTCF had a net balance of $82 million. However, if costs for underground storage tank cleanup related to Ca-RFG-MTBE range from $327-$1400 million annually, there will be a shortage of funds for cleanup needs. In order to cover the costs of the cleanup related to MTBE, the per gallon fee or tax to tank owners should be from $0.048 - $0.21 instead of the current $0.012 fee. An alternative is to impose a tax on gasoline to cover the costs of MTBE-related contamination. The tax would have to be from 2.4 to 10.3 cents per gallon.

Policy 3. After a full environmental assessment of gasoline with ethanol is conducted, increase the use of ethanol as an oxygenate, by developing market incentives for promoting ethanol production in California from agricultural wastes.

The California Department of Food and Agriculture (CDFA) has quantified the percentage of spoilage of various crops for statistics of feedstocks that would be available. The CDFA indicates the most viable sources of feedstock are from residues such as rice straw and orchard residues (Shaffer, 1998). Approximately 1.5 million tons of rice straw are produced each year from the total of 514,720 acres planted in the state of California. Rice straw is considered a waste, which for many years was burned. The Rice Straw Burning Reduction Act of 1991 restricts rice burning, due to serious air emissions problems (CARB, 1997). As of 1998, only 25% of the rice acreage (125,000 acres) can be burned. In 1996, a $15 per ton tax credit was established for rice straw diverted from burning and purchased for commercial use, such as ethanol production (CARB, 1997). There is a cap on the aggregate tax credit of $400,000 each year, which translates to 26,667 tons from 9,000 acres of rice. This represents about 1.7% of the available rice straw.

The Advisory Committee for Rice Straw Alternatives that was created through the 1991 Rice Straw Burning Reduction Act and is jointly appointed by the CARB and CDFA, suggests that the dollar cap of $400,000 be removed in order to promote higher use of rice straw for ethanol production instead of burning. If the dollar cap is removed, 1,470,000 additional tons of rice straw can be directed to ethanol production instead of some form of disposal, at a cost of $22 million in tax credit. This amount could be generated by a tax per acre of cultivated rice of $43. Given that the tax credit is $15 per ton, then the net cost per acre to divert rice straw to ethanol production instead of disposal is $28. An advantage to rice farmers from diverting rice straw to ethanol production is the reduction in the costs of disposing of rice straw. The cost of soil incorporation is estimated to average $36 per acre (CARB, CDFA). Considering the maximum amount of tons devoted to ethanol production through the tax credit for rice straw program, California would be able to produce approximately 135 million gallons of ethanol, which can be used to partially meet the demand for oxygenates.

Two ethanol plants that have been approved for rice straw input to generate the fuel are still awaiting financial assistance. The City of Gridley plant will use 250,000 tons of rice straw to produce 25 million gallons of ethanol per year, with an enzymatic hydrolysis process. The plant will be located near Sacramento, with capital costs of $60 million with an expected lifetime of 60 years. The second plant, by Arkenol, Inc. and the Sacramento Ethanol and Power Cogeneration Project (SEPCO), is an acid hydrolysis plant for production of 12 million gallons of ethanol per year using 182,500 tons of rice straw per year and waste heat from a natural gas turbine. It will be located in Rio Linda and has capital costs of $40 million. Both plants are in need of equity owners that will cover the finances.

The Advisory Committee for Rice Straw Alternatives (Advisory Committee, 1997) recommends government subsidies to address the financial barriers in building these first two plants. The potential rate of return for the investment does not have a high risk; there is a guaranteed market, where Gridley and SEPCO have already identified buyers such as Chevron, and utilities companies in California and the Pacific Northwest. They suggest a government risk sharing on capital investment made in the plant by private investors. Private financial institutions are usually willing to finance between 50 to 60 percent of projects, and developers of the project can provide up to 20 percent of the equity capital. The Committee recommends legislation should be pursued to provide up to 30 percent loan guarantees for the first two facilities. Some potential state agency funding sources for the loan guarantees are the (a) California Pollution Finance Control Authority, (b) the Alternative Energy Financing Authority, and (c) the $5 million Rice Fund for rice straw use other than burning established by CARB and CDFA (CARB, 1997). Currently, Proposition 7 on the November 1998 ballot is proposed to set aside $250 million to fund tax credits for diverting rice straw for ethanol production.

The advantages to California of encouraging increased use of rice straw-to-ethanol are significant. The advantages include (1) reduced open-field burning which reduces the particulate matter (PM_{10}) (20.8 lb/acre burned), reactive organic gases (ROG) which are ozone precursors, nitrogen oxides (NOx), sulfur oxides (Sox) and carbon dioxide emissions (188 lb/acre); (2) employment opportunities in rural areas; (3) reduction of ethanol imports from the Midwest; and (4) alternative to MTBE (CARB, 1997).

A full environmental assessment should be done prior to implementing this policy, to ensure that we do not proceed down the same path as with MTBE, where policy is set without an integral evaluation of the costs and benefits.

Policy 4. Accelerate vehicle retirement programs to achieve air emissions reductions.

Newer vehicles incorporate significant improvements in emissions control technology, including fuel injection, advanced three-way catalytic converters, oxygen sensors and other feedback loops. Older vehicles tend to be high emitters, both due to lack of emission control devices and engine wear. Given that auto emissions increase with vehicle age, accelerated vehicle retirement programs (AVRPs) have become a focus of U.S. air pollution policy and have been implemented in four air basins (San Diego, South Coast, San Joaquin, and San Francisco) in California. Part of the complication in determining the net air quality benefits of CaRFG2 is the almost simultaneous timing of AVRP programs (San Diego and San Francisco) and CARFG2 introduction in 1996.

It is useful to investigate how AVRPs can best be structured to enhance economic efficiency, in other words, achieve pollution reduction in the most cost effective manner. The only emission-related choices that consumers make in choosing to use a vehicle or retire it, beyond mileage, are the automobile's initial features and its retirement age. For a given car, the retirement subsidy declines over time at a rate that reflects the social costs of the vehicle's periodic emissions. Retiring an older car now, as opposed to next year, leads to greater emission reduction benefits because the car is off the road an additional year. An efficient retirement subsidy incorporates this benefit by offering a higher reward for retirement today than for retirement next year. This property is important because, so long as an AVRP is designed as a continuing (rather than a one-shot) program, the program should not give owners of old cars an incentive to hold on to their cars in order to qualify for the program. The AVRP program has linked the subsidy to the predicted emissions from each vehicle. Hence, high-emitting vehicles are given the greatest incentive to retire. Of course, the policy must be designed not to give consumers an incentive to make their cars high-emitting in order to obtain higher retirement subsidies.

We describe the costs of an AVRP in California and explore the potential to augment the program. The figures we use are provided by CARB to estimate air emissions reductions due to technology changes as well as from the South Coast Air Basin Buyback Program. The program is one of four in the state that were established in 1994-present as part of the Ozone State Implementation Plan (SIP), or which can be thought of as California's Clean Air Act. The SIP outlines some goals for reducing air emissions. The M1 Accelerated Retirement Program was designed with the objective of removing 100,000 cars per year. Thus far, the four programs in the state remove approximately 7,000 cars per year. The South Coast Air Basin has removed as many as 10,127 cars (1997), while San Diego, San Joaquin, and the Bay Area Air Quality Management Districts each remove approximately 1200 per year.

The South Coast's program is paid for by industries interested in offsetting air emissions requirements with credits from retiring cars. The SIP outlined guidelines for industries to implement employee ride sharing programs in order to reduce emissions from commuting to work in the Los Angeles air basin. The industries have sought to finance the retirement of old cars instead of implementing these programs. The South Coast's program has specific requirements that correspond to the manner in which the funds are generated to pay for the $600 per car retirement value. The requirements are: that cars have 2 more years of viable life, to parallel the 2 year allowance period that industries have to apply credits. Also, the cars must have been registered for 2 years in Los Angeles air basin where the program is based to affect emissions in that basin.

CARB has projected vehicle fleet age and emissions control technology, from 1995 to 2010 (CARB, 1996, scenario MVEI17G). For simplicity, their data is given in two general classes, cars with catalytic converters and cars without catalytic converters. There are multiple technological changes in between. We use CARB's numbers knowing there are some assumptions involved in making these projections that might abstract from general intuition about what drives technology adoption by drivers such as full information about the existence and attributes of the technology, fully disposable income to make the purchases, and availability of technology throughout the state. The following projections are made for costs associated with the estimated number of cars that will still not have catalytic converters in the years 2000, 2005, and 2010. Assuming that 100% of the fleet would retire in any of those years, means the program would cease once all are retired. Therefore, if the program results in all cars retired in 2000, then there are no remaining non-catalyst cars in 2005 and 2010 to retire.

The interesting economic question is at what time can and should the State of California or the South Coast implement a 100% retirement of these older vehicles. The answer lies in weighing the costs of retirement against the benefits. We calculate the costs of the retirement program using a "scrap value" of $600 per car, which is the current rate used in the vehicle buyback program in Southern California. We calculate the benefits of retirement through CARB's estimates of the emissions reductions made through removal of the vehicles. We make projections for a statewide program and a South Coast program to correspond with CARB data and the existing program in Southern California. Table 12 presents projections of the cost of retiring 100% of the non-catalyst cars in 2000, 2005, and 2010.

Table 12. Cost of Vehicle Retirement Program

	Statewide			South Coast		
Year	2000	2005	2010	2000	2005	2010
Number of cars	660,683	248,910	45,112	268,697	97,110	12,067
100% retirement cost	$396 million	$149 million	$27 million	$161 million	$58 million	$7 million
Re-registration fee	$26 million	$28 million	$30 million	$11 million	$12 million	$12 million

Other schemes for generating the funds to pay for the vehicle retirement program consist of a $1 vehicle re-registration fee through the California Department of Motor Vehicles. Using CARB projections of the total number of cars in use for 2000, 2005, and 2010 statewide and for the South Coast we estimate the revenues available to pay for the retirement program with the $1 re-registration fee (Table 13).

Clearly, it will take time to pay for the vehicle retirement program. This emphasizes the need to explore variations on the number of vehicles retired annually, as well as a different fee to charge to pay for the retirement program. A feasible target for vehicle retirement is 40% (or 40,000 per year) of the vehicles on the road that do not have catalytic converters, and thus much older emissions control devices over the next 10 years. This target would result in removing 200,000 vehicles by the year 2005, leaving 50,000 vehicles without catalytic converters. The emissions reductions would be significant in all four pollutant categories identified above.

A total of 1.5 million vehicles did not have catalytic converter technology as of 1995, but the number of vehicles without catalytic converters is expected to drop to 660,000 by the year 2000. Given a one-dollar increase in the registration fee of the approximately 25 million vehicles in use in California, and a buy-back price of about $600 per vehicle without catalytic converter, we calculate that 40,000 vehicles can be removed per year starting in the year 2000. By the end of the year 2004, the program has removed 200,000 vehicles out of the 660,000 vehicles without catalytic converter still used in 2000, but the normal rate of decommissioning of these vehicles has also removed a large fraction, leaving only about 50,000 vehicles without catalytic converter at the beginning of the year 2005. We assume that the rate of removal of these vehicles then drops to 16,667 per year until the end of the year 2010.

To estimate the reduction in emissions from the buy-back program used to remove motor vehicles with no catalytic converter, and thus much older emissions control devices, we use data from CARB (1996), scenario MVEI17G, as our basis. The emissions reduction is estimated by calculating the difference in emissions per vehicle for a vehicle without catalytic converter to a replacement vehicle with catalytic converter, since we assume that most individuals will replace the vehicle within a short time-frame (one year at most). Based on CARB data, the difference in emissions per vehicle per day for ROG, CO, NOx and SOx is given in Table 13. Note that there is no difference in SOx emissions since the sulfur has been taken out of the gasoline, and the emissions control devices do not target this pollutant. These differences are then multiplied by the number of vehicles removed per year. The first year, 40,000 vehicles without catalytic converter are removed from operation; by the second year 80,000 vehicles have been removed, and so on. The program would be most effective in reducing CO emissions, followed by ROG and to a lesser extent reducing NOx emissions. This calculation has been done on a state-wide basis, but clearly it makes a significant difference whether the emissions are reduced in a non-attainment area or in an air basin which has no significant air pollution concerns.

Table 13. Estimated Difference in Emissions Between Vehicles With and Without Catalytic Converters

ROG	0.17 kg/day
CO	0.76 kg/day
NOx	0.03 kg/day
SOx	0.00 kg/day

AVRPs can be a very cost effective method of reducing emissions. Within a given generation of vehicle technology there is a fraction of vehicles which will emit at much higher levels, either due to poor maintenance, tampering with the emissions control devices, modification of the carburetor or the inappropriate use of leaded gasoline which then poisons the catalyst. Knepper et al. (1993) studied the effects of using oxygenated fuels in some high emitting vehicles. Typically the vehicles run fuel rich. The vehicles studied, from the 1986-87 model year, had CO emissions ranging from 17 g/mi to 216 g/mi, compared with the 3.4 g/mi CO emission standard set by USEPA in 1981. These vehicles also had high HC emissions (1.5 to 15 g/mi), but low NOx emissions, given their fuel rich condition. The use of oxygenated fuels resulted in a statistically significant reduction in CO and HC emissions. A study by Mayotte et al (1994a,b) also found a reduction in CO and HC emissions when gasoline was oxygenated with either ethanol or MTBE. A field study by Bishop and Stedman (1990) found that 7-10% of the vehicles, out of 4,900 vehicles identified by make and model, produced about 50% of the CO emissions. Retiring these high emitters achieves air quality objectives without the corresponding threat to water resources that oxygenates present.

Policy 5. Management of surface water reservoirs, both temporally and spatially, to reduce the levels of contamination.

Santa Clara Water Agency has recently gained considerable experience in implementing restrictions on surface water reservoirs. Their results may be useful for developing successful programs for the rest of the state. Some of the options that Santa Clara considered and implemented on their reservoirs follow:

a) Banning all gasoline-powered recreational watercraft on some or all reservoirs.

b) Restricting the number of recreational watercraft used on some or all reservoirs, spatially and temporally

c) Banning CaRFG-MTBE use for boating applications

d) Replacement and maintenance of engines, fuel tanks, and other equipment of boats, and/or development of new technologies

e) Public education to prevent fuel leakage

f) No action

The state-wide estimate of the total travel cost for the recreational gasoline-powered boating is $160 to $200 million. This figure represents the total value of recreational boating in lakes and reservoirs in the State of California and thus equals to the estimated lost values per year from banning all boating on all those reservoirs. It is the cost of full enforcement of the policy option (a) throughout the state. Clearly this option has economic and political implications, and is unlikely to be feasible.

Policy option (b) has been implemented in Santa Clara County Parks as part of a boating-management plan. Their plan began May 1, 1998. This plan limits the number of powered watercraft on certain reservoirs, and also applies fees for boating on Calero Reservoir. (Santa Clara County Parks, 1998; Santa Clara Valley Water District, 1998]. Data on the number of recreational boats used in this reservoir (Santa Clara County Parks and Recreation Department, 1998) show a decline in the number of boats due to these restrictions. The decline is on the order of 1500 boats over May, June, July, and August.

The cost of this management plan in terms of recreation can be estimated with following calculation. Foregone boating expenses (entrance fees, gasoline, distance traveled) are summed using data from Calero Reservoir in Santa Clara County where restrictions on personal water craft during the summer of 1998 consisted of limits on the numbers of boats for two months and then an outright ban of all boats when MTBE levels in the reservoir exceeded acceptable levels.

The travel cost that is lost due to the management plan

= Launch fee + Gasoline price for boating + Driving cost + Driving time cost
= $13,083 + $18,000 + $1,305 + $1,913
= $34,301

This figure accounts for 22.8% of the total travel cost for (or value in terms of) recreational boating in Calero Reservoir.

Policy (c) would involve costs of monitoring of vehicles at the recreational site. At the same time the entrance and launching fees are paid, the monitoring of vehicles for the fuel type could be accomplished. The policy has not been implemented yet, and is not feasible until non-oxygenated CaRFG2 is widely available in this region. A more rigorous assessment of monitoring costs should be quantified.

Policy (d) is beginning to be implemented by resource management agencies such as the East Bay Municipal Utilities District (EBMUD). The EBMUD has invested in new boating technology. The costs for replacing 154 two-stroke marine engines with new 4-stroke engines is $300,000. Installation costs for the replacement are approximately $60,000. By dividing the sum of $360,000 by 154, we derive a per engine cost of replacement of $2,300, which we can use to multiply by the statewide number of engines that would be replaced for recreational use in waterways (Tikkanen, 1998). Data on the total number of boat engines used in freshwater reservoirs is not available.

Policy (e) is currently carried out in Santa Clara County in the form of signage and management practices at the reservoirs, to increase awareness of the problem. The practices include limiting gasoline refueling to launch ramps, instead of refueling on the water and posting visual aids for disseminating the water quality levels on a weekly basis. The total costs of these practices has not been quantified, but is expected to be relatively low, and should be to encourage similar practices in other locations. A rough estimate would be $1,000 to $5,000 per reservoir, for an aggregate state cost of $115,000 to $750,000.

Policy (f) would result in costs of water treatment from not having controlled the source of contamination from motorcraft emitting directly to the water, which is on the order of $4 to $30 million annually. This is the most expensive policy option for surface water reservoirs.

6. Conclusions

We set out to answer the three questions posed in the introduction, which are crucial for policymakers. We have assessed the costs and benefits of various gasoline formulations, based on the available information and using various valuation methods. There are significant uncertainties in our estimates, but we are confident that the overall results of our study are well founded and provide a scientific basis for policymakers.

Based on the results of the CBA, the costs of using MTBE outweigh the benefits. There are alternative gasoline formulations that can achieve the air quality benefits of CaRFG2 without the additional risks to California's water resources, and costs of water treatment. The comparative CBA analysis indicates that non-oxygenated CaRFG2 achieves air quality benefits with the least costs, resulting in a net benefit. CaRFG2 with ethanol has net costs in achieving air quality benefits. CaRFG2 with MTBE has the highest net costs for achieving air quality benefits. The most important cost factors for MTBE are the cost of water treatment to avoid human health damages, the direct cost increase and the potential lost value of recreational boating.

A set of policy options has been evaluated in terms of their costs and benefits. Restricting the use of oxygenated gasoline to non-attainment areas during only certain months can result in a net cost decrease of $100 to $300 million to California's consumers. The costs of cleaning up MTBE-contaminated aquifers should be internalized, either as an additional surcharge on USTs or as a direct tax on gasoline, to reflect the true cost of CaRFG2 with MTBE, and to provide adequate funding for pending clean-up. After an integral assessment of CaRFG2 with ethanol is performed, the use of rice straw as feedstock for producing ethanol can result in significant advantages, both from an economic and an environmental perspective. Accelerated vehicle retirement programs can be much more cost-effective in reducing air pollutant emissions than the use of oxygenates; a full evaluation of the timing and value of emissions reduction should be performed to justify these programs. Surface water reservoirs can be managed to reduce the costs of MTBE contamination, while preserving some or all of their recreational value. These policies are not exclusive but rather complementary. These policies should be pursued as soon as possible, to reduce risk and costs.

There are several areas that require further research to reduce the uncertainties in the CBA. Adequate dose/response information at low concentrations is crucial to any evaluation of the air quality benefits and costs. The toxicology of the combustion by-products of MTBE and ethanol needs to be defined quantitatively. Predictive models of the expected increase in atmospheric concentrations of oxygenates and their combustion by-products can reduce the uncertainty in these estimates, in particular for ethanol. The leakage rate of upgraded UST is the most important uncertainty in determining the potential future costs of groundwater remediation; adequate pipeline failure rate statistics are also important. An expanded assessment of the recreational value of California's lakes and reservoirs could be made with data from additional sites.

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Table 14. List of Reservoirs Used for both Water Supply and Gasoline Powered Recreational Boating

No.	Name of Reservoir	Location (County)	Status	Points	Capacity(AF)	Class	Point	Pt.Sum	Class	Travel Cost
1	Lake Almanor	Plumas	Major	3	1143000	Large	3	6	1	$ 16,000,000
2	Anderson Lake	Santa Clara	Usual	1	89100	Medium	2	3	4	$ 482,057
3	Antelope Lake	Plumas	Usual	1	22600	Small	1	2	5	$ 150,000
4	Beardsley/Hartley Lake	Tuolumne	Usual	1	97800	Medium	2	3	4	$ 482,057
5	Lake Berryessa	Napa	Major	3	1600000	Large	3	6	1	$ 16,000,000
6	Bethany Forebay/Res.		Usual	1	4900	Small	1	2	5	$ 150,000
7	Big Bear Lake	San Bernardino	Major	3	73000	Medium	2	5	2	$ 4,978,664
8	Black Butte Reservoir	Glenn/Tehama	Equipped	2	143700	Medium	2	4	3	$ 1,549,193
9	Boca Reservoir	Nevada	Usual	1	41100	Small	1	2	5	$ 150,000
10	Bowman Lake	Nevada	Usual	1	68500	Medium	2	3	4	$ 482,057
11	Bridgeport Reservoir	Mono	Equipped	2	42600	Small	1	3	4	$ 482,057
12	Lake Britton	Shasta	Equipped	2	40600	Small	1	3	4	$ 482,057
12	Bucks Lake	Plumas	Equipped	2	105600	Medium	2	4	3	$ 1,549,193
13	(New) Bullards Bar Reservoir	Yuba	Equipped	2	966103	Large	3	5	2	$ 4,978,664
14	Butt Valley Reservoir	Plumas	Usual	1	49900	Small	1	2	5	$ 150,000
15	Cachuma Lake	Santa Barbara	Usual	1	190500	Medium	2	3	4	$ 482,057
16	Camanche Reservoir	Amador/Calaveras/San Joaquin	Major	3	417120	Medium	2	5	2	$ 4,978,664
17	Camp Far West Lake/Res.	Yuba/Placer	Usual	1	104000	Medium	2	3	4	$ 482,057
18	Caples Lake	El Dorado	Usual	1	21600	Small	1	2	5	$ 150,000
19	Lake Casitas	Ventura	Usual	1	254000	Medium	2	3	4	$ 482,057
20	Castaic Lake	Los Angeles	Usual	1	323700	Medium	2	3	4	$ 482,057
21	Cherry Lake		Usual	1	268000	Medium	2	3	4	$ 482,057
22	Clear Lake	Lake	Major	3	313000	Medium	2	5	2	$ 4,978,664
23	Coyote Reservoir	Santa Clara	Usual	1	22300	Small	1	2	5	$ 150,000
24	Lake Crowley	Mono	Usual	1	183200	Medium	2	3	4	$ 482,057
25	Cuyamaca Lake/Res.	San Diego	Usual	1	12200	Small	1	2	5	$ 150,000
26	Lake Davis	Plumas	Usual	1	84400	Medium	2	3	4	$ 482,057
27	Lake Del Valle	Alameda	Usual	1	77100	Medium	2	3	4	$ 482,057
28	Donner Lake	Nevada	Usual	1	9700	Small	1	2	5	$ 150,000
29	(New) Don Pedro Reservoir	Tuolumne	Equipped	2	2030000	Large	3	5	2	$ 4,978,664
30	East Park Reservoir	Colusa	Usual	1	50900	Medium	2	3	4	$ 482,057
31	Eastman Lake		Usual	1	150000	Medium	2	3	4	$ 482,057
32	El Capitan	San Diego	Usual	1	112800	Medium	2	3	4	$ 482,057

No.	Name of Reservoir	Location (County)	Status	Points	Capacity(AF)	Class	Point	Pt.Sum	Class	Travel Cost
33	Englebright Reservoir	Nevada/Yuba	Equipped	2	70000	Medium	2	4	3	$ 1,549,193
34	Florence Lake	Fresno	Usual	1	64600	Medium	2	3	4	$ 482,057
35	Folsom Lake	Placer/Sacramento/El Dorado	Equipped	2	977000	Large	3	5	2	$ 4,978,664
36	French Meadows Reservoir	Placer	Usual	1	136400	Medium	2	3	4	$ 482,057
37	Frenchman Lake/Res.	Plumas	Equipped	2	55477	Medium	2	4	3	$ 1,549,193
38	Grant Lake	Mono	Major	3	47600	Small	1	4	3	$ 1,549,193
39	Lake Havasu	San Bernardino/Arizona St.	Major	3	619400	Large	3	6	1	$ 16,000,000
40	Hell Hole Reservoir	Placer	Usual	1	207600	Medium	2	3	4	$ 482,057
41	Lake Hemet	Riverside	Usual	1	13500	Small	1	2	5	$ 150,000
42	Lake Hennessey	Napa	Usual	1	31000	Small	1	2	5	$ 150,000
43	Lake Henshaw	San Diego	Usual	1	53400	Medium	2	3	4	$ 482,057
44	Hensley Lake		Usual	1	90000	Medium	2	3	4	$ 482,057
45	Lake Hodges	San Diego	Usual	1	33600	Small	1	2	5	$ 150,000
46	Huntington Lake	Fresno	Usual	1	89800	Medium	2	3	4	$ 482,057
47	Ice House Reservoir	El Dorado	Usual	1	45960	Small	1	2	5	$ 150,000
48	Indian Valley Reservoir	Lake	Usual	1	301000	Medium	2	3	4	$ 482,057
49	Iron Canyon Reservoir	Shasta	Usual	1	24200	Small	1	2	5	$ 150,000
50	Lake Isabella	Kern	Equipped	2	568000	Large	3	5	2	$ 4,978,664
51	Jackson Meadows Reservoir	Nevada/Sierra	Equipped	2	69200	Medium	2	4	3	$ 1,549,193
52	Jenkinson Lake	El Dorado	Usual	1	41000	Small	1	2	5	$ 150,000
53	Lake Jennings	San Diego	Usual	1	9800	Small	1	2	5	$ 150,000
54	Lake Kaweah	Tulare	Usual	1	143000	Medium	2	3	4	$ 482,057
55	Kerchkhoff Reservoir		Usual	1	4247	Small	1	2	5	$ 150,000
56	Keswick Reservoir	Shasta	Usual	1	23800	Small	1	2	5	$ 150,000
57	Lake Valley Reservoir	Placer	Usual	1	8000	Small	1	2	5	$ 150,000
58	Lewiston Lake	Trinity	Usual	1	14700	Small	1	2	5	$ 150,000
59	Little Grass Valley Reservoir	Plumas	Equipped	2	94700	Medium	2	4	3	$ 1,549,193
60	Los Banos Reservoir	Merced	Usual	1	34600	Small	1	2	5	$ 150,000
61	Lower Bear Reservoir	Amador	Usual	1	52025	Medium	2	3	4	$ 482,057
62	Lower Otay	San Diego	Usual	1	49500	Small	1	2	5	$ 150,000
63	Mammoth Pool Reservoir	Madera	Usual	1	122700	Medium	2	3	4	$ 482,057
64	McCloud Reservoir/Lake	Shasta	Usual	1	35200	Small	1	2	5	$ 150,000
65	Lake McClure/Exchequer Res.	Mariposa	Major	3	1024600	Large	3	6	1	$ 16,000,000
66	Lake McSwain	Mariposa	Major	3	9730	Small	1	4	3	$ 1,549,193
67	Lake Mendocino	Mendocino	Usual	1	122400	Medium	2	3	4	$ 482,057
68	Millerton Lake	Madera/Fresno	Equipped	2	520000	Large	3	5	2	$ 4,978,664

No.	Name of Reservoir	Location (County)	Status	Points	Capacity(AF)	Class	Point	Pt.Sum	Class	Travel Cost
69	Lake Miramar	San Diego	Usual	1	7200	Small	1	2	5	$ 150,000
70	Modesto Reservoir		Usual	1	29000	Small	1	2	5	$ 150,000
71	Morena Lake/Res.	San Diego	Usual	1	50200	Medium	2	3	4	$ 482,057
72	Murray Reservoir	San Diego	Usual	1	4800	Small	1	2	5	$ 150,000
73	Lake Nacimiento	San Luis Obispo	Equipped	2	340000	Medium	2	4	3	$ 1,549,193
74	Lake Natoma	Sacramento	Usual	1	9000	Small	1	2	5	$ 150,000
75	New Hogan Lake/Res.	Calaveras	Equipped	2	317100	Medium	2	4	3	$ 1,549,193
76	New Melones Reservoir	Calaveras/Tuolumne	Equipped	2	2420000	Large	3	5	2	$ 4,978,664
77	O'Neil Forebay	Merced	Usual	1	56400	Medium	2	3	4	$ 482,057
78	Lake Oroville	Butte	Major	3	3537600	Large	3	6	1	$ 16,000,000
79	Pardee Reservoir/Lake	Amador/Calaveras	Usual	1	197950	Medium	2	3	4	$ 482,057
80	Perris Lake/Res.	Riverside	Equipped	2	131500	Medium	2	4	3	$ 1,549,193
81	Lake Pillsbury	Lake	Equipped	2	80500	Medium	2	4	3	$ 1,549,193
82	Pine Flat Dam/Lake	Fresno	Equipped	2	1000000	Large	3	5	2	$ 4,978,664
83	Pinecrest Lake	Tuolumne	Usual	1	18300	Small	1	2	5	$ 150,000
84	Lake Piru	Ventura	Usual	1	88346	Medium	2	3	4	$ 482,057
85	Prosser (Creek) Reservoir	Nevada	Usual	1	29800	Small	1	2	5	$ 150,000
86	Pyramid Lake	Los Angeles/Ventura	Usual	1	171200	Medium	2	3	4	$ 482,057
87	Redinger Lake		Usual	1	35000	Small	1	2	5	$ 150,000
88	Rollins Reservoir/Lake	Nevada/Placer	Equipped	2	66000	Medium	2	4	3	$ 1,549,193
89	Ruth Lake/Res.	Trinity	Usual	1	51800	Medium	2	3	4	$ 482,057
90	Saddlebag Lake	Mono	Usual	1	11100	Small	1	2	5	$ 150,000
91	Salt Springs Reservoir	Amador/Calaveras	Usual	1	141857	Medium	2	3	4	$ 482,057
92	Lake San Antonio		Equipped	2	330000	Medium	2	4	3	$ 1,549,193
93	San Luis Reservoir (CVP)	Merced	Usual	1	971000	Large	3	4	3	$ 1,549,193
94	San Pablo Reservoir	Contra Costa	Usual	1	38600	Small	1	2	5	$ 150,000
95	San Vicente Reservoir	San Diego	Usual	1	90200	Medium	2	3	4	$ 482,057
96	Santa Margarita Lake	San Luis Obispo	Usual	1	23000	Small	1	2	5	$ 150,000
97	Scotts Flat Reservoir	Nevada	Usual	1	48500	Small	1	2	5	$ 150,000
98	Lake Shasta	Shasta	Major	3	4552000	Large	3	6	1	$ 16,000,000
99	Shaver Lake	Fresno	Usual	1	135400	Medium	2	3	4	$ 482,057
100	Silver Lake	El Dorado/Amador	Usual	1	8590	Small	1	2	5	$ 150,000
101	Lake Silverwood	San Bernardino	Usual	1	73000	Medium	2	3	4	$ 482,057
102	Skinner Lake	Riverside	Usual	1	44200	Small	1	2	5	$ 150,000
103	Sly Creek Reservoir	Butte	Usual	1	65700	Medium	2	3	4	$ 482,057
104	South Lake	Inyo	Usual	1	12900	Small	1	2	5	$ 150,000

No.	Name of Reservoir	Location (County)	Status	Points	Capacity(AF)	Class	Point	Pt.Sum	Class	Travel Cost
105	Spaulding Lake	Nevada	Usual	1	75100	Medium	2	3	4	$ 482,057
106	Stampede Lake/Res.	Sierra	Usual	1	226500	Medium	2	3	4	$ 482,057
107	Stony Gorge Reservoir	Glenn	Equipped	2	50000	Medium	2	4	3	$ 1,549,193
108	Stumpy Meadows Lake	El Dorado	Usual	1	20000	Small	1	2	5	$ 150,000
109	Lake Success	Tulare	Equipped	2	82300	Medium	2	4	3	$ 1,549,193
110	Lake Tahoe	Placer/El Dorado	Major	3	732000	Large	3	6	1	$ 16,000,000
111	Tulloch Reservoir	Calaveras/Tuolumne	Usual	1	67000	Medium	2	3	4	$ 482,057
112	Turlock Lake	Stanislaus	Usual	1	49000	Small	1	2	5	$ 150,000
113	Union Valley Reservoir	El Dorado	Equipped	2	277300	Medium	2	4	3	$ 1,549,193
114	Whiskeytown Lake	Shasta	Equipped	2	241100	Medium	2	4	3	$ 1,549,193
115	Lake Wishon	Fresno	Usual	1	128300	Medium	2	3	4	$ 482,057

Major: Major Recreational Site; Equipped: seems Well Equipped, Usual: appears 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