

## **Cost Benefit Analysis of MTBE and Alternative Gasoline Formulations**

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## **Abstract**

This paper presents a cost-benefit analysis of the 1990 Clean Air Act Amendments (CAAA) requiring the addition of oxygen content in gasoline, using California as a case study. The valuation and comparison of costs and benefits for several fuel blends (with and without oxygen content) provides a framework to investigate cross-media (air, water, soil) tradeoffs. We use known valuation methods such as the travel cost method to derive recreational value, the averting expenditures approach and cost of illness approach to derive public health costs, and market price method to quantify increases in fuel price and fuel efficiency costs in order to compare the alternatives. We use data from California to evaluate the current fuel blend with Methyl tert-Butyl Ether (MTBE), a fuel blend with ethanol (ethyl alcohol), and a fuel blend without oxygenated compounds. The most expensive option to meet the 1990 CAAA is the current reformulated gasoline blend with MTBE, which results in a net cost to California's economy of between \$0.9 and 2.7 billion dollars annually. The cost of treating groundwater contaminated with MTBE is a major cost factor. Our assessment indicates that the non-oxygenated gasoline formulation is the most cost-effective, particularly in the long-term, once refiners are able to implement modifications to their installations or negotiate long-term supply contracts for these additives. Several strategies are identified to transition out of using the current gasoline blend with MTBE.

## 1 Introduction

The introduction of gasoline additives to address air pollution, mandated by the 1990 Clean Air Act (CAA) Amendments, has not been carefully evaluated in terms of costs and benefits of the policy decision until our study. The widespread water contamination in California and elsewhere that resulted from using Methyl tertiary-Butyl Ether (MTBE), a gasoline additive, has emphasized the need for conducting comprehensive analyses of costs and benefits of fuel blends that have tradeoffs or cross-media effects on air, water, and land.

The reauthorization of the CAA of 1990 introduced a requirement for oxygen content in gasoline in the interest of improving air quality through reductions in emissions of carbon monoxide and reactive organic gases. To meet the oxygen content requirement, gasoline manufacturers have used MTBE, ethanol and other additives, denominated oxygenates since they contain oxygen. The statewide introduction of reformulated gasoline in the State of California to meet the CAA Amendments resulted in widespread use of MTBE, without a full environmental impact assessment. MTBE comprises about 11 to 15% by volume of the reformulated gasoline used in California since 1996.

The cost-benefit analysis (CBA) of fuel alternatives presented here represents a new approach to analyzing cross-media impacts of major regulations. Previous CBA studies that have been done in this area do not specifically focus on alternatives meeting cross-media objectives. For example, a recent study focused on the costs and benefits of the CAA of 1970 (USEPA, 1997); this study only considers the impact of reducing criteria air pollutants, without addressing specific policies to achieve them, such as modifications to fuel formulations, new vehicle technologies, or emission control technologies on fixed sources. There is no evaluation of the impact on soil or water due to the generation of scrubber waste, for example. Schwing et al. (1980) used a CBA to compare leaded and unleaded fuels, using an aggregate index of hydrocarbon emissions; they attributed all positive health effects to carbon monoxide reductions, without acknowledging the effects of lead reduction or elimination. Another study compared methanol to conventional gasoline in terms of reducing motor vehicle emissions and urban ozone, yet avoided discussing health effects or potential impacts on water quality (Krupnick and Walls, 1992).

The CBA entails use of valuation methods to derive quantitative measures of costs and benefits of gasoline blends. These costs and benefits are evidence used by the Governor of California in his decision to ban MTBE. The study provides answers to the following questions:

- 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?

## 2 Method

In this CBA, we evaluate three gasoline formulations that meet California's Phase II Reformulated Gasoline (CaRFG2) requirements: CaRFG2 with MTBE, CaRFG2 with ethanol, and non-oxygenated CaRFG2. The first two formulations comply with the Federal oxygen content mandate. The third formulation is allowable through the California Air Resources Board (CARB) Predictive Model for evaluating components of fuel blends.

All costs and benefits for the different gasoline formulations evaluated are estimated relative to conventional gasoline, the typical gasoline formulation sold before the implementation of the 1990 CAA, and still available in many states where Federal air quality standards are achieved. As part of the CaRFG2 regulations, CaRFG2 has to be sold throughout the state of California (CARB, 1991). To simplify the analysis, we assume that each fuel alternative 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 to use MTBE. This study explores costs not accounted for in using MTBE and other fuel alternatives and provides the information to make more complete decisions, on a micro- (individual refiner) and macroeconomic (state or nation-wide) level.

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

- Air quality benefits in terms of human health
- Human health costs due to air or water pollution derived from the oxygenates
- Water treatment or alternative water supply costs
- Fuel price increase costs
- Costs due to increased fuel consumption
- Monitoring costs
- Recreational costs
- Ecosystem damages

The second stage is a systematic comparison of each alternative, based on the net benefits of each fuel blend and technology 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). Table 1 presents a brief summary of the valuation techniques we use 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 health 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. We use data from epidemiology research for valuing public health costs and benefits that consists of estimates of population percentages exposed to air and water-borne pollutants from the fuel alternatives we are comparing (Froines et al., 1998).

Engineering estimates and market prices are used to establish 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. For example, we use data from the city of Santa Monica for the water quantity and expenditures made to purchase water from an alternative supply to avoid contamination, given that a significant fraction of their groundwater supply is contaminated with MTBE.

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 also is 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 annual costs and benefits of each alternative fuel given the available data. 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.

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).

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, there is a large uncertainty in the valuation of the effects of reducing air pollutant levels on human health once they are below the air quality standards, or even when they are slightly above, since the toxicological data is at much higher concentrations.

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 from jet ski emissions on health to flora and fauna. We use the recreational cost of using a jet ski plus the value of the environmental health damages from gasoline discharges to surface waters. We explain in detail the assumptions used in the valuation approaches developed throughout the study.

### 3 Results

#### 3.1 Air Quality Benefits of Reformulated Gasoline

##### *Air Toxics*

Koshland et al. (1998) found that all the CaRFG2 formulations (MTBE, ethanol or non-oxygenated) are 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. CaRFG2 has no significant influence on emissions of other criteria pollutants, toxics or particulates. There is no statistically significant difference between any one of the formulations in terms of the reduction of emissions of these four air pollutants. Of these four pollutants, benzene has the most significant impact on human health (ATSDR, 1991; IARC, 1985). Benzene can increase the incidence of leukemia and is classified as a group A carcinogen (known human carcinogen). USEPA has classified 1,3-butadiene as a Group B2, probable human carcinogen of medium carcinogenic hazard (USEPA, 1993a).

To derive a value for air quality benefits due to reduced mortality from cancer we note the following. The reduction in benzene concentrations in California's air basins since the introduction of CaRFG2 ranges from 0.06 to 0.16 parts per billion (ppb) per year (Figure 1). 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, gasoline 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. Using cancer risk factors (cancer potency), we estimate the potential decrease in cancer risk per million people. 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. Multiplying this result by the population exposed to benzene, we obtain the potential reduction in cancer risk for California. To translate this into a monetary value, we use the value of a statistical life of \$5 million (adjusting for inflation by 4% from Fisher et al, 1989). The calculations are presented in Table 2. The reduction in benzene concentrations translates into a potential reduction of 33 to 920 cancer cases per year, which are valued at \$165 million to \$4.5 billion dollars over a lifetime (70 years).

A similar evaluation of the impact of RFG on 1,3-butadiene atmospheric concentrations since 1996 shows no statistically significant trend. This toxic pollutant is generally found at very low concentrations within California (0.02 to 0.45 ppb), and the

effect of any oxygenate on 1,3-butadiene concentrations is expected to be minor in any case (AQIRP, 1997). Thus, we did not consider any significant economic benefit in this regard.

### ***Carbon Monoxide***

To derive a value of air quality benefits associated with reduced morbidity effects from decreases in carbon monoxide we note the following. Carbon monoxide (CO) increases the levels of carbon monoxide bound to hemoglobin (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). Linkage of cardiovascular disease to CO is evident from increased hospital visits during air pollution episodes (Morris et al., 1995; Schwartz and Morris, 1995). Morris et al. (1995) used air quality data from 1986 to 1989 in seven U.S. cities (including Los Angeles) and hospital admissions due to congestive heart failure. The authors estimated that hospital admissions due to chronic heart failure increase by 37% for a 10 parts per million (ppm) increase in CO concentrations in Los Angeles. If the response is monotonic, a 1 ppm increase (from the National Ambient Air Quality Standard of 9 ppm to 10 ppm) should result in an increased hospital admission risk of 1.032 for people with ischemic heart disease.

Carbon monoxide levels prior to the introduction of CaRFG2 were less than 15 ppm in practically all air basins in California. Only 3 monitoring stations in California exceeded the NAAQS in 1996, and the downward trend in concentrations since the late 1970s continues (USEPA, 1999). At present, there is only one non-attainment area in California for carbon monoxide, namely the South Coast air basin. Figure 2 presents the trend in maximum daily 8-hr average CO concentrations in the South Coast from 1991 to 1997, on a monthly basis. The peaks (shown as boxed values) occur during the winter months. This trend reflects the success of many different CARB policies over the last decade, with a steady decline even before the widespread use of oxygenated gasoline. The maximum CO concentrations registered in this region since 1994 are around 11 ppm; these levels are only observed a few days during each month, and are concentrated in episodes.

The decrease in maximum CO is around 0.7 ppm. Considering the epidemiological data from Morris et al. (1995), this would represent a decrease of 840 hospital admissions per year in the South Coast Basin. This estimate is likely to be an overestimate of the beneficial effect of MTBE, since not all people with ischemic heart disease will experience the peak in CO concentrations within the South Coast air basin, and thus will not benefit from the decrease in the peak. The average length of stay for chronic heart failure was 7.9 days, using 1992 data (NCHS, 1996). Multiplying 840 admissions by the cost of hospital expenses for heart failure (\$9,968, that is in 1997 dollars used with 4% inflation from Krupnick et al., 1996) yields a sum of \$8,373,120. Accounting for an average of one week of restricted activity from chronic heart failure after the hospital stay is done by multiplying the value of \$216 per day (in 1997 dollars used with 4% inflation from Tolley et al, 1986) by the 7 days and the total number of cases (840) to arrive at \$1,270,080. The total value of benefits from avoiding morbidity due to carbon monoxide is the sum of hospital and restricted days avoided which equal \$9,643,200.

## *Ozone*

To derive the value of air quality benefits associated with reduced morbidity effects from decreases in ozone we note the following. 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. The inflammatory response to ozone can be detected even after just one hour of exposure to 0.30 ppm (USEPA, 1998b) It can be accompanied by symptoms such as chest pain, coughing, nausea, and pulmonary congestion (Kleinman et al., 1991). Sensitive individuals are affected at levels above 0.15 ppm (Breslin, 1995). California has set a 1-hour standard of 0.09 ppm.

Recent studies provide evidence of an association between elevated ozone levels and increases in hospital admissions for respiratory problems in several U.S. cities (Burnett et al., 1997; Morris et al., 1995; Dab and Quenel, 1994). Burnett et al. (1997) specifically controlled for sulfur dioxide, nitrogen dioxide, carbon monoxide, soiling index, and dew point temperature, and determined that a 30 ppb (0.030 ppm) increase in ozone concentrations results in an increased relative risk of hospitalization due to respiratory illness of 1.024 to 1.043, depending on the cities included (all Canadian) in the correlation. The rate of hospitalization for acute respiratory illness in the U.S., as of 1992, is 1.48 per 1000 people, with an average stay of 4.0 days (NCHS, 1996). Assuming that the rate is approximately the same across the nation, then the number of hospitalizations for the South Coast region due to acute respiratory illness would be around 14,000 per year.

Ozone concentrations in the South Coast air basin (and other ozone non-attainment areas in California) are highest during the summer months (Figure 3). Although the number of days the California standard is exceeded has decreased noticeably, from a high of 261 days of exceedance in 1981 to around 135 to 180 days of exceedance in recent years (CARB, 1999), the levels are significantly above the 0.09 ppm level. Dab and Quenel (1994) argue that there is no threshold level for ozone's respiratory effects; any exceedance over the 0.09 ppm level may result in an increase in hospital admissions.

The air quality data suggests that there has been a faster decrease in ozone concentrations since the introduction of reformulated gasoline, of approximately 12 to 15 ppb per year. Considering the study by Burnett et al. (1997), this would result in a decreased risk of hospitalization of 1.134 to 1.168. For the population affected by high ozone levels in California, this could represent a decrease of 1650 hospitalizations per year due to avoided acute respiratory illness. Multiplying 1650 by the cost of hospital expenses for acute respiratory illness (\$5044, that is in 1997 dollars used with 4% inflation from Krupnick et al., 1996) yields a sum of \$8,323,000. Accounting for an average of one week of restricted activity from respiratory illness after the hospital stay is done by multiplying the value of \$ 43 per day (in 1997 dollars used with 4% inflation from Tolley et al, 1986) by the 7 days and the total number of cases (1650) to arrive at \$496,650. The total value of benefits from avoiding morbidity due to ozone is the sum of hospital days and restricted days avoided which equal \$8,819,650.

As we have stressed before, ambient concentrations may vary widely, spatially and temporally, even within an air basin. To simplify this analysis we have assumed that the 1-hr average ozone concentration is uniformly distributed, which tends to result in an overestimate of the benefits.

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 will be much smaller than at the introduction of CaRFG2. We therefore expect the human health benefits of CaRFG2 to decrease over the next few years. It is also important to consider the decreases in human health benefits of MTBE or oxygenates due to changes in the emissions control technology of the vehicle fleet. It has been shown that adding MTBE or other oxygenates to reformulated gasoline does not reduce carbon monoxide emissions in newer vehicles, within statistical significance (AQIRP, 1997; Koshland, 1998). Thus, the benefits of adding oxygenate to gasoline formulations are relatively small and decreasing with time. The benefits presented in this section are valid for any one of the three CaRFG2 formulations (with MTBE, with ethanol, or without oxygenated), since all of them produce essentially the same reduction in emissions of air toxics, carbon monoxide and ozone precursors.

### **3.2 Air Quality Costs of Reformulated Gasoline**

#### ***Reformulated Gasoline with MTBE***

To value the public health costs from use of the oxygenate MTBE we note the following. 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 significant 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). 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%, which translate into a potential increase 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 in terms of costs of illness and mortality, as calculated in Table 2.

#### ***Reformulated Gasoline with Ethanol***

To value the public health costs from ethanol we note the following. The use of ethanol as an oxygenate, substituting MTBE, could result in significant increases in acetaldehyde emissions as a combustion byproduct (AQIRP, 1997), with a corresponding increase in atmospheric concentrations. USEPA has designated acetaldehyde as a B2 probable human carcinogen (USEPA, 1993b, 1987; CARB, 1993; IARC, 1985). A study in New Mexico documented an increase of 1-2 ppb in acetaldehyde concentrations after

using ethanol/gasoline mixtures (Gaffney et al., 1997). We estimate that the increase in the South Coast air basin could be of the same magnitude. The total cost may be from \$3 to \$200 million dollars. However, it should be mentioned that ethanol has been used in the Midwestern U.S. with no noticeable increase in acetaldehyde concentrations. A more complete study is required to determine whether there is really a concern with the use of ethanol.

### *Non-Oxygenated CaRFG2*

To produce non-oxygenated CaRFG2, the most likely replacements of MTBE are toluene or isooctane. Either one of these chemicals would provide high enough octane rating and combustion efficiency to meet the goals of the 1990 CAA. One immediate concern is the potential increase in toluene or isooctane 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<sup>3</sup> or 400 µg/m<sup>3</sup> (USEPA, 1993d). In California, the mean concentration in air is 8.5 µg/m<sup>3</sup>. This concentration could increase significantly and still not be close to the RfC, where adverse effects would be measurable. None of the data suggest that toluene is carcinogenic. Two epidemiological studies did not detect a statistically significant increased risk of cancer due to inhalation exposure to toluene. However, these studies had many confounding factors. Animal studies have been negative for carcinogenicity. EPA has classified toluene as a Group D, not classifiable as to human carcinogenicity. 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. Isooctane is not classified as a hazardous air pollutant by USEPA, and there is no toxicological information from the Agency for Toxic Substances and Disease Registry (ATSDR). It is a normal component of gasoline, and with acute effects on the central nervous system when inhaled at high concentrations, but the risk is similar to conventional gasoline.

## **3.3 Direct Costs of CaRFG2 additives**

### **3.3.1 CaRFG2 with MTBE**

It is 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 (1 gallon = 3.785 L) 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 (not oxygenated) 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.

The following studies are acknowledged for a range of price changes attributed to MTBE derived through other approaches:

1) 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).

2) 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.

Considering our estimates and the previous studies, it seems reasonable to assume a premium for RFG of approximately 1 to 5 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 \$135 to \$675 million.

#### ***Fuel Consumption of RFG with MTBE***

Fuel consumption increases 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% increase in fuel consumption 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 is from \$310 to \$400 million. Monzon and Kennedy (1998) reviewed studies that examined the cost of increased maintenance and decreased engine performance due to the use of RFG, and found that there is no significant increase or decrease in maintenance costs or changes in engine performance associated with the use of RFG.

#### ***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 potential savings due to the octane enhancement value of MTBE.

#### **3.3.2 CaRFG2 with Ethanol**

The California Energy Commission has conducted a study of the supply and cost of fuel alternatives to MTBE that includes ethanol (CEC, 1999). The CEC approach is to consider the additional cost that California would incur by having to purchase the necessary ethanol on the market to meet California's demand if MTBE was banned.

Based on a total annual gasoline consumption in California, conversion to ethanol as the primary oxygenate would result in a demand of 75,000 b/d (barrels per day, 1 barrel = 0.158 m<sup>3</sup>) of ethanol from other locations. Total potential domestic capacity for ethanol production is approximately 80,000 b/d. California could "bid away" blocks of ethanol

capacity from other regions based on a price premium (CEC, 1998b). Transportation costs and costs of equipment for blending at terminals are included in the calculation of obtaining ethanol from midwestern U.S. producers and Brazilian producers. The estimated unit price increase ranges from 1.9 cents per gallon to 6.7 cents per gallon. This implies a cost range of \$290 to \$991 million per year.

### ***Fuel Consumption***

Ethanol has an energy content that is significantly less than that of the ethers (like MTBE) 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%). The increased fuel consumption has been estimated to be up to 3% relative to non-oxygenated fuel (NSTC, 1997). Given that the current annual statewide consumption of gasoline is on the order of 13.9 billion gallons per year (905,000 b/d), the estimated increase in consumption is 209 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.

### **3.3.3 Non-oxygenated CaRFG2**

The additional cost of producing a non-oxygenated fuel is estimated by CEC (1998b) for a toluene-enriched or iso-octane mixture that is 90% gasoline blended with 10% toluene or iso-octane. The non-oxygenated fuel eliminates the need to import oxygenates and reduces the use of crude oil by about 120,000 b/d which save the refiners more than \$6.3 million per day. However, even with this savings, there are costs of producing blending material at California refineries and importing additional gasoline components. The price increase is from 0.9 to 8.8 cents per gallon or from \$141 million to \$1.3 billion per year.

### ***Fuel Consumption***

The energy content of non-oxygenated gasoline will increase by about 0.8 to 1.2% depending on the amount of toluene or iso-octane 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 Aggregate Cost of Water Treatment in California**

The annualized cost (i.e. total cost divided by the number of years considered for treatment) 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 been 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 \$327 to \$1,400 million above the cost that would have been incurred if conventional

gasoline without MTBE had been used (Tables 3 and 4). Unit water treatment costs were prepared based on experimental studies, by Keller et al. (1999). Groundwater remediation costs include the legacy of older leaking USTs that stored gasoline with MTBE, which will cost from \$320 to \$1,030 million per year to remediate in the next few years. The projected cost of future leaks of MTBE from upgraded USTs is between \$7 million and \$370 million.

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 (without MTBE) had still been used (Table 3). We sum up the costs for each gasoline type and evaluate the extra cost to treat MTBE-contaminated sites. The difference is important since approximately 80% of conventional gasoline leaks are dealt with through natural attenuation (dilution, dispersion and biodegradation), whereas we estimate that only 10% of MTBE/gasoline leaks can be naturally attenuated. Since MTBE does not biodegrade significantly under natural conditions, it is only attenuated by dispersion, which results in much higher concentrations arriving at monitoring or drinking water wells. Most other gasoline components degrade rapidly and thus can attenuate significantly (Rice et al., 1995).

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. Considering 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, 1999) are considered. 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 of surface water reservoirs that will become contaminated above the Secondary Drinking Water Standard (5 ug/L). In addition, it is unknown whether through management of the reservoir by the water suppliers the treatment costs

can be reduced or eliminated. 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 contamination in each source. The annualized cost of treating water supplies contaminated with MTBE, relative to the cost that would have been incurred if conventional gasoline without MTBE had been used, is summarized in Table 4.

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. 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. If iso-octane is used instead of MTBE, it has a very low solubility in water, and it is readily biodegraded along with other components of conventional gasoline. 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.

### **3.5 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.

### **3.6 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 samples taken per month (typically 10 per reservoir, with significant variability in the number of samples), the analytical cost (ranging from \$100 to \$200 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 and there are 100 to 150 used for recreational boating. Experience has shown that specific monitoring for MTBE is done only in those drinking water reservoirs that 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 the previous section on the cost of water treatment. 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 California Department of Health Services (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.

### **3.7 Recreational Costs**

One way to rapidly reduce the impact of motorized boating on multiple-use lakes and reservoirs for potable water is to ban or restrict watercraft that use gasoline with MTBE. Reuter et al. (1998) show different motorboat engines 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 use data of waterways throughout California that would be subject to boating restrictions to estimate the change in consumer surplus associated with the change in available boating recreation. 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. 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 5.

The following example from Santa Clara County illustrates the calculation of travel costs for the various classes of reservoirs that would be subject to boating restrictions. According to the data for Calero Reservoir in Santa Clara County from California Department of Water Resources (CAL-DWR, 1998), a class 5 reservoir, 4,391 boats launched in the one-year period from April 1<sup>st</sup>, 1997 to March 31<sup>st</sup>, 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. Those who bought annual permits visited Calero Reservoir seven times a year on average. The total fee can be estimated as follows:

$$\begin{aligned} \text{Total fee} &= [\text{number of annual permits issued}] \times [\text{price of annual permit}] + [\text{number} \\ &\quad \text{of daily entrance fees paid}] \times [\text{daily launch fee}] \\ &= [4,391 \times 0.45 / 7] \times [\$50] + [4,391 \times 0.55] \times [\$10] = \$38,264 \end{aligned}$$

The Parks Department notes an average boat uses 10 gallons of gasoline per day, which costs \$1.20 per gallon. With this figure we obtain the total price of gasoline that is used for boating through following calculation:

$$\text{Total fuel cost} = [4,391 \text{ boats}] \times [\$1.20 \text{ per gallon}] \times [10 \text{ gallons}] = \$52,692$$

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:

$$\begin{aligned} \text{Driving costs} &= [4,391 \times 0.90 \text{ cars}] \times [5 \text{ miles}] \times [\$1.20 \text{ per gallon}] / [20 \text{ miles per} \\ &\quad \text{gallon}] + [4,391 \times 0.10 \text{ cars}] \times [100 \text{ miles}] \times [\$1.20 \text{ per gallon}] / [20 \\ &\quad \text{miles per gallon}] = \$1,186 + \$2,635 = \$3,820 \end{aligned}$$

We assume that on average there are two people per boat, with opportunity costs of travel time based on 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:

$$\begin{aligned} \text{Driving time cost} &= [4,391 \times 0.90 \text{ cars}] \times [2 \text{ people}] \times [0.25 \text{ hours}] \times [\$15 \text{ per hour}] + \\ &\quad [4,391 \times 0.10 \text{ cars}] \times [2 \text{ people}] \times [2 \text{ hours}] \times [\$15 \text{ per hour}] = \\ &\quad \$29,639 + \$26,346 = \$55,985 \end{aligned}$$

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 + Boat Fuel + 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):

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

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 data from Calero Reservoir and from Lake Tahoe (class 1), we estimate the total travel cost for each class, as shown in Table 6. The two reservoirs place a lower and upper bound on our estimate.

Summing over all reservoirs, we derive the state-wide estimate of the total travel cost for the recreational gasoline-powered boating of 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 for the total value of recreational boating in lakes and reservoirs in the State of California that are also used as drinking water reservoirs. This estimate provides an upper bound on the value of recreational boating that may be lost if all motorized watercraft are banned.

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

### **3.8 Ecosystem Damages**

Based on the ecological risk assessment by Werner and Hinton (1998), the concentrations of MTBE that have been detected in lakes and water reservoirs should not result in significant damages to biota in aquatic ecosystem. 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.

### **3.9 Cost-Benefit Analysis**

The results of the CBA for each CaRFG2 formulation are presented in Table 7. 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 \$0.9 - \$2.7 billion, which would rank it last out of the three fuel alternatives. 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.

In some instances, 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 source of the contamination there may be some local damages, 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 7, 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) are presented in parenthesis.

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 be 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.

## **4 Discussion**

The results of the CBA, along with other supporting studies, have been used by the Governor of California to direct a phase-out of MTBE in California (Davis, 1999). A review of the effects of MTBE has led the USEPA's Blue Ribbon Panel on Oxygenates in Gasoline to recommend a nation-wide "phase-down", with some members of the reviewing panel recommending a phase-out as well (U.S. EPA, 1999).

The CBA offers the comprehensive accounting of costs and benefits that oil companies using MTBE and regulators missed when choosing this oxygenate for gasoline. Recently, upon realizing the costs, some entities have begun to look for

alternatives (Chevron and Tosco companies). While a more complete CBA would take into consideration dynamic effects, it is clear that we should look for alternatives to MTBE, since the costs far outweigh the benefits. In addition, the air quality benefits are decreasing with time, while the water treatment costs would likely increase with time if MTBE continues to be used.

For the CBA, we assumed that only one fuel formulation is used 100% throughout the state for each alternative. In reality, all three formulations are currently being commercialized. While 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 (Keller et al., 1998). These policies are not mutually exclusive, and may be implemented in various combinations in order to transition out of the most expensive fuel (CaRFG2 with MTBE):

- Restrict use of CaRFG2 with oxygenates to Federal air quality non-attainment areas during non-attainment periods. In this way, it is possible to provide flexibility while still meeting air quality objectives.
- Internalize the cost of MTBE-contaminated water treatment through a charge on underground storage tanks and gasoline through extension of the Underground Storage Tank Fund.
- Develop market incentives for producing ethanol from agricultural waste in California.
- Accelerate vehicle retirement programs to achieve air emissions reductions.
- Manage surface water reservoirs temporally and spatially to reduce the levels of contamination.

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. There are savings from allowing for flexibility across a spatially diverse state instead of applying one restriction uniformly. 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. Through the existing Underground Storage Tank Cleanup Fund, it is possible to adjust the tax to tank owners to \$0.048-\$0.21 in order to generate ample funds for cleanup into the new century (Keller et al, 1998). Otherwise a direct tax on gasoline would have to be from 2.4 to 10.3 cents per gallon to cover the costs of cleanup. 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. Existing programs such as the tax credit program for converting rice straw from a burned waste to ethanol could potentially provide 10% of California's ethanol demand. 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. The existing programs for vehicle retirement in the four most populated air districts can be augmented through a \$1 vehicle re-registration fee that would result in removing 40% (or 40,000 per

year) of the highest emitting vehicles (Keller et al., 1998). Surface water reservoirs can be managed to reduce the costs of MTBE contamination, while preserving some or all of their recreational value. The management can take the form of limited permits for watercraft, technological changes in engines and watercraft, and public education to prevent fuel loss into waterways such as has been implemented in Santa Clara, Alameda, and Contra Costa counties. These policies are not exclusive but rather complementary, and should be pursued as soon as possible, to reduce risk and costs.

## **5 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.

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.

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 USTs 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 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  |
| Water Treatment                                 | Avoidance expenditures | Value using costs of goods to avoid risk, Abdalla et al., 1992          |
|   | 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               |

**Table 2. Economic Value of Changes in Atmospheric Concentrations.**  
(Values in 1998 dollars)

|  | Benzene <sup>1</sup>                               | Formaldehyde <sup>2</sup>                          | Acetaldehyde <sup>3</sup>                          |
|--|--|--|--|
| Cancer Risk Factor<br>ppb <sup>-1</sup>            | 2.72 x 10 <sup>-5</sup> to 1.92 x 10 <sup>-4</sup> | 3.08 x 10 <sup>-7</sup> to 4.06 x 10 <sup>-5</sup> | 1.75 x 10 <sup>-6</sup> to 4.86 x 10 <sup>-5</sup> |
| Estimated change in concentration <sup>4</sup>     | (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 | (\$2.4) to (\$65) million                          | \$0 to \$27 million                                | \$2.7 to \$200 million                             |

<sup>1</sup>For any CaRFG2 formulation. <sup>2</sup>Due to MTBE. <sup>3</sup>Due to Ethanol <sup>4</sup>Parenthesis denote decrease

**Table 3. Aggregate Annualized Cost of UST Treatment**

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

**Table 4. Aggregate Annualized Cost of Water Treatment<sup>1</sup>**

|                  | 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 |

<sup>1</sup>relative to conventional gasoline

**Table 5. 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      |

↓

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

**Table 6. Total Travel Cost per Reservoir and Class**  
(assuming a \$15 per hour wage rate)

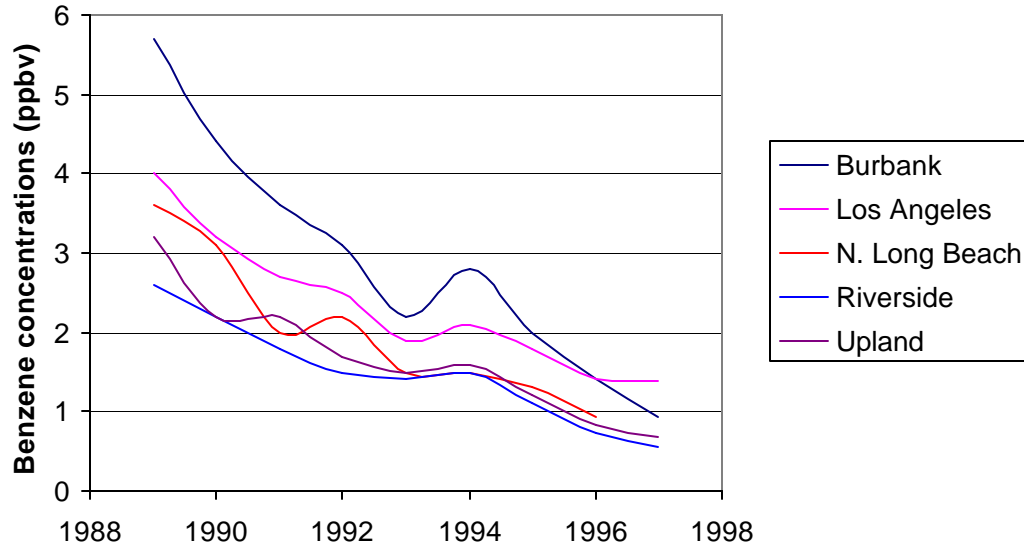
| Classes | Travel Cost for each reservoir | Number of reservoirs | Total travel cost for each class |
|---------|--------------------------------|----------------------|----------------------------------|
| 1       | \$10,600,000                   | 7                    | \$74,200,000                     |
| 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                    |

**Table 7. Annualized Cost Benefit Analysis of Fuel Alternatives**

|                          | CaRFG2-MTBE                | CaRFG2-Ethanol             | Non-oxy CaRFG2             |
|--------------------------|----------------------------|----------------------------|----------------------------|
| Air Quality Benefits     | \$2 to \$84 million        | \$2 to \$84 million        | \$2 to \$84 million        |
| Health Costs             |                            |                            |                            |
| air quality damages      | \$0 to \$27 million        | \$3 to \$200 million       | N.S. <sup>1</sup>          |
| water treatment          | \$340 to \$1480 million    | N.S. <sup>1</sup>          | \$1 to \$10 million        |
| alternate water supplies | \$1 to 30 million          | N.S. <sup>1</sup>          | N.S. <sup>1</sup>          |
| Direct Costs             |                            |                            |                            |
| fuel price increase      | \$135 to \$675 million     | \$290 to \$991 million     | \$141 to \$1300 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. <sup>1</sup>          | N.S. <sup>1</sup>          |
| recreational costs       | \$160 to \$200 million     | N.S. <sup>1</sup>          | N.S. <sup>1</sup>          |
| ecosystem damages        | N.S. <sup>1</sup>          | N.S. <sup>1</sup>          | N.S. <sup>1</sup>          |
| Costs Subtotal           | \$0.9 to 2.8 billion       | \$0.6 to \$1.8 billion     | (\$0.09) to \$1.2 billion  |
| Net Benefit or (Cost)    | (\$0.9) to (\$2.7) billion | (\$0.5) to (\$1.8) billion | \$0 to (\$1.2) billion     |

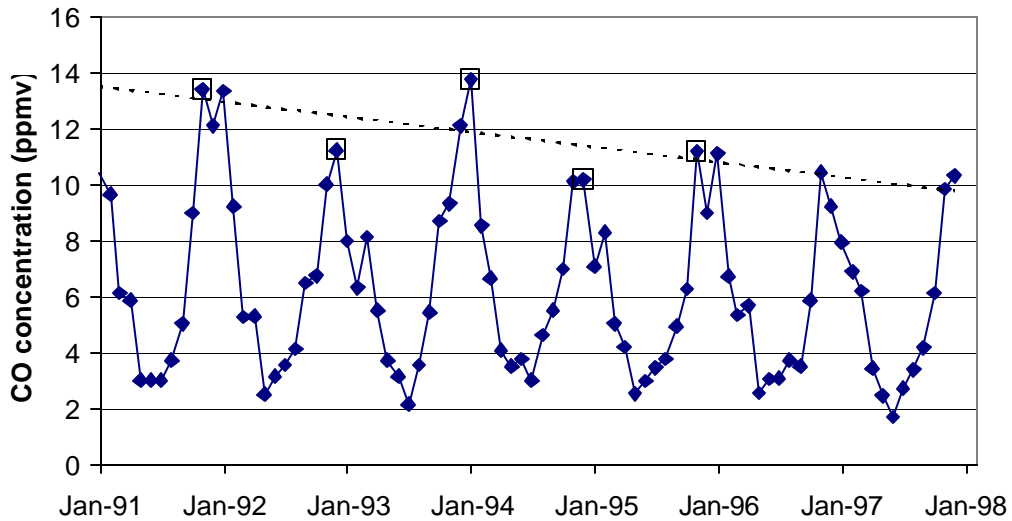
<sup>1</sup>Not significant

**Figure 1. Trend in Benzene concentrations in the South Coast Air Basin<sup>1</sup>**



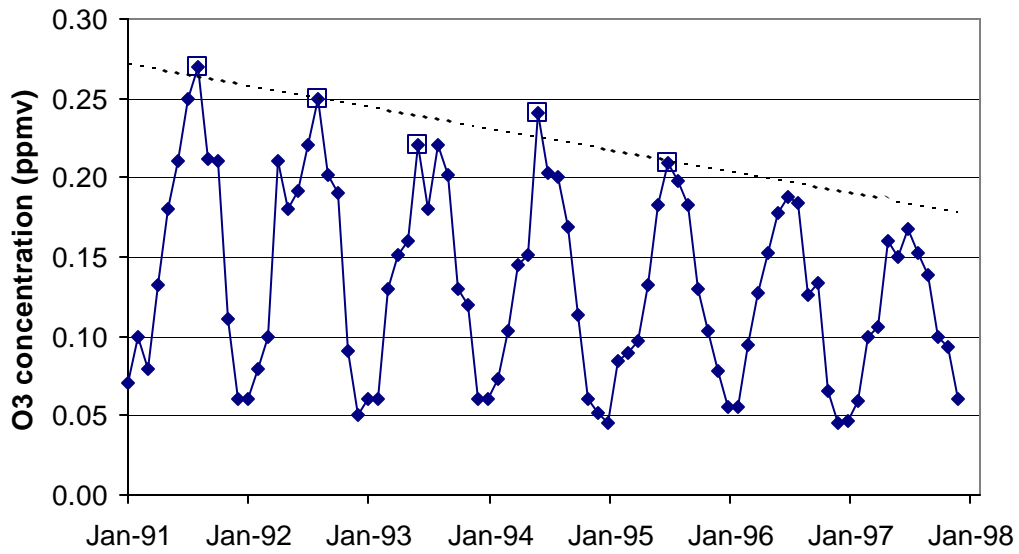
<sup>1</sup>Source: California Air Resources Board, 1998

**Figure 2. Trend in maximum Carbon Monoxide concentrations in South Coast Air Basin<sup>1</sup> (8-hr average, 90 percentile)**



<sup>1</sup>Source: California Air Resources Board, 1998

**Figure 3. Trend in maximum Ozone concentrations  
in South Coast Air Basin<sup>1</sup>  
(1-hr average, 90 percentile)**



<sup>1</sup>Source: California Air Resources Board, 1998