

Cost Benefit Considerations for the Introduction of Gasoline Additives such as MTBE

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Abstract

The introduction of gasoline additives to address air pollution, such as MTBE, has to be carefully evaluated to take into consideration all the costs and benefits associated with the policy decision. The recent experience in the US, and in particular in California, indicates that there are significant costs associated with these additives, when the entire health and environmental impact is assessed. MTBE is highly soluble, and thus transfers easily to groundwater and surface water bodies, either as a result of gasoline leaks or spills. It presents possible health concerns and definitely affects the taste and odor quality of the water. Thus, the air quality benefits achieved by better combustion of the improved gasoline formulation may be superceded by water treatment costs. In addition, there are several other cost categories that have to be taken into consideration in such policy decisions, such as monitoring costs, ecological damages, and restrictions on recreational activities. Complicating the policy making process, one has to take into account the fact that air quality benefits decrease with time, since vehicle technologies are improving, such that the reduction in emissions is not necessarily only due to the gasoline additive, but also to other factors. The current work presents an analysis of the situation in California, as well as a discussion on the aspects of the cost-benefit analysis which may differ for situations such as Mexico City, Beijing, Athens or other cities with rather different air pollution levels and vehicle technologies.

Introduction

The search for solutions to air quality problems has led to the development of gasoline additives which can have a positive impact on the combustion efficiency, significantly reducing emissions of carbon monoxide, ozone precursors and hazardous air pollutants, such as benzene. However, a careful consideration of the impact of these gasoline additives on other media must be made for each circumstance. The case of Methyl tert-Butyl Ether (MTBE) has served to highlight the potential for cross-media contamination at large scales, when the environmental impact assessment is incomplete.

A recent study by Keller et al. (1998a), as part of a wider evaluation of the health and environmental impacts of MTBE (Keller et al., 1998b), concluded that the air quality benefits for California, derived from the use of MTBE as a gasoline additive at 11 to 15% by volume, were relatively small, and are decreasing with time. The decrease is based on the fact that other policies and technologies implemented to reduce air emissions are becoming more important as the vehicle fleet modernizes. Older vehicles (pre-1990) do not have many of the emissions control devices (e.g. advanced catalytic converters, oxygen sensor feedback, fuel injection), and thus may emit large amounts of carbon monoxide and other air pollutants. The addition of MTBE (or other oxygenated compounds) can reduce the emissions of carbon monoxide from older vehicles. In addition, MTBE is used to replace some of the high octane rating that benzene and other

aromatics provide; the substitution reduces the aromatic fraction of the gasoline and thus lowers the emission of air toxics.

The cost-benefit analysis conducted for California examined the human health benefits derived from controlling air pollution, and then systematically analyzed the costs associated with the use of MTBE across the following categories:

- Human health costs due to air pollution from MTBE and its combustion byproducts
- Human health costs due to water pollution derived from MTBE
- Water treatment or alternative water supply costs
- Fuel price increase costs
- Costs due to increased fuel consumption
- Monitoring costs
- Recreational costs
- Ecosystem damages

Although cost-benefit analysis has been used extensively to evaluate alternative policies, there have been to date no studies that examine the cross-media implications of different gasoline (or other fuels) formulations. For example, a recent study focused on the costs and benefits of the Clean Air Act of 1970 (USEPA, 1997), but considered only the impact of reducing criteria air pollutants on human health, without addressing specific policies to achieve the reductions, such as modifications to fuel formulations, new vehicle technologies, or emission control technologies on stationary sources. Schwing et al. (1980) used cost benefit analysis to compare leaded and unleaded fuels, but did not consider the impact of leaded fuels on water supplies. In developing countries where MTBE is being evaluated as a substitute for tetraethyl lead, the water quality damages associated with the use of leaded fuels must also be considered. Krupnick and Walls (1992) 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.

For policy makers charged with deciding between gasoline formulations to achieve improved air quality, a cost benefit analysis can provide answers to the following questions:

- Do the costs of using MTBE outweigh 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?
- How do alternative formulations compare in terms of costs and benefits?

Methodology

The first step in the analysis is to identify the benefits and cost categories. In addition to the categories indicated in the introduction, it is possible to add other costs, such as litigation, or replacement land for sites contaminated with MTBE, or the cost of drilling

new wells for public drinking water supply. The number of categories considered depends to a large extent on the availability of adequate data; some cost categories have too much uncertainty associated with them, or may be deemed not as significant as the principal cost categories. Although there may be cultural differences that place a different value on some of the cost categories, we believe that for most studies the categories we have identified will serve to make adequate policy decisions.

The next step is to identify alternative policies, or in our case, alternative formulations. In the case of MTBE, there are gasoline formulations which use ethanol, toluene or iso-octane, which can provide essentially the same air quality benefits (AQIRP, 1997; Koshland et al., 1998), with different costs. In addition, since we were interested in determining the cost of adding MTBE, we used as our baseline conventional unleaded gasoline, which was the gasoline formulation sold prior to the introduction of the reformulated oxygenated gasolines in California and other parts of the U.S. Table 1 presents the typical composition of these gasoline formulations.

Complete details of the methods used to value each benefit or cost category are presented in Fernandez and Keller (1999) or Keller et al. (1998a). Briefly, health benefits were valued using cost of illness (Abdalla et al., 1992) or the value of a statistical life (Fisher et al., 1989), depending on whether the pollutant causes morbidity, mortality, or both. The health effects associated with MTBE and other pollutants were derived from the study by Froines et al. (1998). Water treatment costs were based on experimental and field studies conducted by Keller et al. (1998c, 1999), plus data from Reuter et al (1998) on the number of water reservoirs that are contaminated, and Fogg et al. (1998) on the number of groundwater sites requiring treatment. With this information, we were able to integrate an estimate of the cost of water treatment for the State of California.

Market prices were used to estimate the direct cost paid by consumers at the pump due to the mandated use of oxygenated fuels. The increase in gasoline consumption was based on engineering estimates of the decrease in fuel energy content (NSTC, 1997), which result in an increased cost of operation. Market prices were 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).

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.

Results

Figures 1-3 present the cost and benefits for the three formulations studied (gasoline with MTBE, gasoline with ethanol, and non-oxygenated gasoline, with either toluene or iso-octane). The health benefits are essentially the same across all three formulations, since studies have shown that all these formulations achieve essentially the same carbon monoxide and ozone precursors emissions reductions, within statistical significance. An additional benefit achieved in the California Phase II Reformulated Gasoline formulations (CARB, 1991), is the reduction of benzene content. Benzene is a known human carcinogen (ATSDR, 1991; IARC, 1985), and the reduced content (less than 1%) in reformulated gasoline results in decreased volatile emissions. We have estimated that this alone reduces 33 to 920 cancer cases per year in California. The uncertainty in this estimate is derived largely from the uncertainty in the cancer potency factor. In addition, we estimate that the reduction in carbon monoxide may have decreased the number of hospital admissions due to congestive heart failure by up to 840 cases per year. Similarly, the reductions in ozone concentrations may lead to a reduction in hospital admissions due to acute respiratory illnesses of up to 300 cases per year. However, it is difficult to determine the fraction of the air pollutant's reduction due strictly to the fuel formulation, or due to other factors such as vehicle technology, meteorology, driving patterns, economic activity, etc. Thus, these estimates should be seen as an upper bound. Significant as they are with respect to human health, we estimate that these benefits only represent around \$14 to \$78 million per year.

There are several reasons why these benefits are small in California:

There have been many programs successfully implemented by the California Air Resources Board to reduce the emissions of air pollutants, and thus the overall concentrations of carbon monoxide and ozone are much lower than in previous decades. For example, carbon monoxide levels prior to the introduction of the current version of oxygenated, reformulated gasoline were less than 12 ppm in practically all air basins in California. The National Ambient Air Quality Standard (NAAQS) for carbon monoxide is 9 ppm for an 8-hour average. 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. 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 when adverse meteorological conditions intersect with high levels of emissions. Thus, the benefit of oxygenating the gasoline is small, since it is generally considered that the NAAQS are set such that if they are attained there is no health impact even to sensitive populations. A decrease of 2 ppm in peak carbon monoxide concentrations would only benefit people with ischemic heart disease, which represent around 3 % of the population. In addition, only a fraction of this population would be affected enough to require hospitalization (Morris et al., 1995; Graves and Owings, 1998).

Similarly, ozone concentrations have been declining even in the South Coast region over the last two decades. However, in this case, 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 California standard of 0.09 ppm (1-hour average) during the summer months, peaking at 0.18 to 0.20 ppm. The decrease in ozone concentrations due to the oxygenate could be up to 0.015 ppm, which would benefit sensitive populations with reduced respiratory function (Burnett et al., 1997).

The average age of the vehicle fleet has decreased in recent years, due to the economic recovery in southern California since 1993. This means that newer vehicles with improved emissions controls are replacing older vehicles. In addition, programs implemented to remove older vehicles are reducing the number of high emitters.

The emissions from stationary sources and other mobile sources (trucks, airplanes, ships, trains, etc.) are becoming more important relative to emissions from vehicles that use gasoline with MTBE. Programs to control emissions from these other sources lag the successful control of emissions from vehicles.

These conditions may be quite different in other cities and air quality basins, in particular in developing countries. For example, Mexico City has seen increasing ozone and carbon monoxide concentrations in the past few years. A program targeted at these air pollutants would have a major impact on human health. In addition, the vehicle fleet is much older, and instead of a somewhat steady state vehicular population, it is increasing rapidly. Transportation bottlenecks and adverse meteorological conditions compound the problem. Thus, a full evaluation of the health benefits for these situations should be conducted prior to making any decision to use or ban MTBE. And alternative formulations (e.g. non-oxygenated) should also be considered.

There are air quality costs associated with the new gasoline formulations. For example, the use of MTBE results in volatilization of MTBE (from fuel lines, fueling stations, pipelines, etc.). In addition, the combustion of MTBE increases the emissions of formaldehyde (AQIRP, 1997, Koshland et al., 1998) in controlled combustion studies. Formaldehyde is a known human carcinogen (USEPA, 1993a, 1988; IARC, 1985). Although the observed MTBE concentrations are below the cancer risk level (Froines et al., 1998), the potential increase in formaldehyde concentrations could result in up to 380 cancer cases per year, negating some of the benefits of reducing benzene emissions. It should be noted that to date, the concentration of formaldehyde in various Californian cities has shown no upward (or downward) trend since the introduction of MTBE

Similarly, adding ethanol to gasoline (as a replacement of MTBE) increases the emissions of acetaldehyde (Gaffney et al., 1997; AQIRP, 1997, Koshland et al., 1998). Acetaldehyde is also a probable human carcinogen (USEPA, 1993b, 1987; CARB, 1993; IARC, 1985). If the concentrations were to increase as they did in New Mexico during the introduction of ethanol-gasoline mixtures, by 1-2 parts per billion (ppb), the number of cancer cases could increase to 2,800 per year. 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.

If either toluene or iso-octane are used to replace MTBE in non-oxygenated formulations, the concentrations of either chemical would increase in ambient air.

However, the levels of toluene would probably be below the Reference Concentration (RfC) in air of 0.4 mg/m³ or 400 μ g/m³ (USEPA, 1993c; ATSDR, 1992). In California, the mean concentration in air is 8.5 μ g/m³. 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. Iso-octane 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 thus can produce acute effects on the central nervous system when inhaled at high concentrations, but the risk is similar to conventional gasoline. There have been limited studies of the combustion byproducts of these formulations, so it is highly recommendable to make a full assessment before proceeding to their wide-scale introduction.

The introduction of reformulated gasoline with MTBE resulted in an estimated price increase of 1 to 5 cents per gallon. This translates into a cost to the economy of \$135 million to \$675 million. In addition, due to the lower energy content of MTBE (NSTC, 1997), there is an additional cost to the California economy of \$300 to 380 million due to the increase in fuel consumption to maintain the same driving pattern. A recent study by the CEC (1999) estimated that the cost of using ethanol as a substitute for MTBE would be around 1.9 to 6.7 cents per gallon, or an annual cost of \$260 to 900 million. The increase in fuel consumption due to the use of ethanol would cost an additional \$560 million (a 3% increase in consumption). For non-oxygenated gasoline, CEC (1999) estimates a price increase from 0.9 to 8.8 cents per gallon, or \$121 million to \$1.3 billion per year. The CEC estimates that in the short term (1-3 years), the price increase would be at the high end of the range (4.3 to 8.8 cents per gallon), whereas once refiners have been able to install the necessary equipment or long-term import contracts are established (3-6 years), the price increase should be only around 0.9 to 3.7 cents per gallon. However, in this case, the use of either toluene or isooctane would result in decreased fuel consumption, due to the higher energy content of these chemicals, saving the economy from \$150 to 220 million.

Fogg et al., (1998) and Reuter et al. (1998) estimated the number of groundwater supplies, leaking fuel tanks and surface water reservoirs that are currently contaminated with MTBE. Based on their information, and the study by Keller et al. (1998c), we made an estimate of the aggregate cost of water treatment in California, of around \$340 to 1,480 million per year (Table 1). These costs are based on the premise that contaminated water must be treated to a concentration below the 5 μ g/L level set by California's EPA as the Secondary Water Quality Standard, based on taste and odor considerations.

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 isooctane 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.

Some utilities may be forced to purchase water from other supplies, at least in the short to intermediate term. For example, the city of Santa Monica has been purchasing water from the Metropolitan Water District due to the contamination of most of their drinking water wells with MTBE. The cost per year for alternate water supply, assuming that 20% of the contaminated water has to be replaced at a cost of \$1.65/1000 gallons that Santa Monica pays for water from the Metropolitan Water District (Rodriguez, 1997), is around \$1 million to \$30 million. These costs would not be significant for other gasoline formulations, relative to conventional gasoline.

There are some incremental monitoring costs, since water utilities are required to sample more frequently, in particular in surface water reservoirs where boating is allowed. Statewide, this cost is expected to amount to \$1 million to \$4 million. For groundwater sources, the current costs could increase to \$1 and \$2 million annually. 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.

One alternative that can be considered for minimizing the impact of MTBE is banning motorcraft from surface water reservoirs. If boating was completely eliminated from all the reservoirs in California, we estimate that the cost, in terms of recreational value lost, would be on the order of \$160 to \$200 million. It is likely that only a partial ban would be implemented, and probably not a year-round ban. MTBE is volatile enough to quickly escape to the atmosphere from a contaminated reservoir, in the order of weeks. We consider that this cost would not be significant for ethanol-based gasoline formulations or non-oxygenated gasoline, relative to conventional gasoline.

Ecological risk assessment studies by Werner and Hinton (1998) indicate that 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.

Discussion

Comparing the bottom line for each formulation (Figure 4), it is clear that for California, using MTBE in reformulated gasoline is a very expensive option. The costs far outweigh the benefits. More significantly, the benefits are small and decreasing with time, as the vehicle fleet modernizes, incorporating emissions control technologies. The main cost driver is water treatment, based on the very tight standards set for MTBE in California. Ethanol-based formulations don't fare much better, although the mid-point of the costs range is smaller than the mid-point of the MTBE formulation. The biggest uncertainty is the impact of a much larger demand for ethanol, which could drive prices up significantly, at least in the short term. One hidden advantage of ethanol is the fact that it can be produced from agricultural wastes such as rice straw, reducing greenhouse emissions. Many developing countries have the potential of producing ethanol from these sources, thus reducing their dependence on imported oil, while improving their air quality.

Non-oxygenated gasoline formulations are apparently the best option for California. There is currently one refiner commercializing a non-oxygenated formulation that meets the strict California Phase II Reformulated Gasoline specifications, except for the oxygen content, presumably at a profitable price. However, the technologies may not be available to the entire industry. Capital expenditures are needed to convert to these formulations. In the mean time, imported toluene or isooctane may drive the costs towards the high end of the range. However, if air quality must be maintained, this appears to be the lowest cost strategy for California. An important consideration is the need to evaluate the toxicology (human and ecological) and fate and transport of any gasoline additives before making drastic changes. The mistakes made with MTBE should be avoided at all costs.

For developing countries, there are a number of factors that must be considered when choosing gasoline formulations. First, an assessment of the air quality benefits must be made, to evaluate whether the change in formulations is warranted. This requires information on trends of ambient air concentrations of pollutants, average vehicle age and technology, as well as number of hospitalizations from congestive heart failure and acute respiratory illnesses, and their cost. Next, an assessment of the vulnerability of water sources must be made. The use of Geographical Information Systems, which can overlay well locations with the location of underground storage tanks, can serve to make an assessment of vulnerability. An inventory of leaking tanks is also needed. California also was able to reduce the impact on water resources due to the decade-long program to upgrade underground storage tanks. If the tanks do not have double-containment and leak detectors, the probability of failure is around 2% per year (Couch and Young, 1998), and the water treatment costs will certainly overwhelm the air quality benefits.

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Table 1. Composition of Gasoline Formulations

<i>Property</i>	<i>Typical Conventional Gasoline</i>	<i>Oxygenated CaRFG2</i>	<i>Typical CaRFG2 with MTBE</i>	<i>Non- oxygenated CaRFG2¹</i>
Aromatics, (vol. %)	32.0	max. 25.0	25	22.7
Olefins, (vol. %)	9.2	max. 10.0	4.1	4.6
Benzene, (vol. %)	1.53	max. 1.0	0.93	0.94
Oxygen content (%)	0	1.8-2.7	2.1	0
Sulfur (ppm by weight)	339	max. 40	31	38
Reid Vapor Pressure (psi)	8.7	max. 7.0	6.8	6.9
T90, °F	330	max. 300	293	297
T50, °F	218	max. 210	202	208

¹based on AQIRP (1997)

Figure 1. Cost and Benefits of Reformulated Gasoline with MTBE

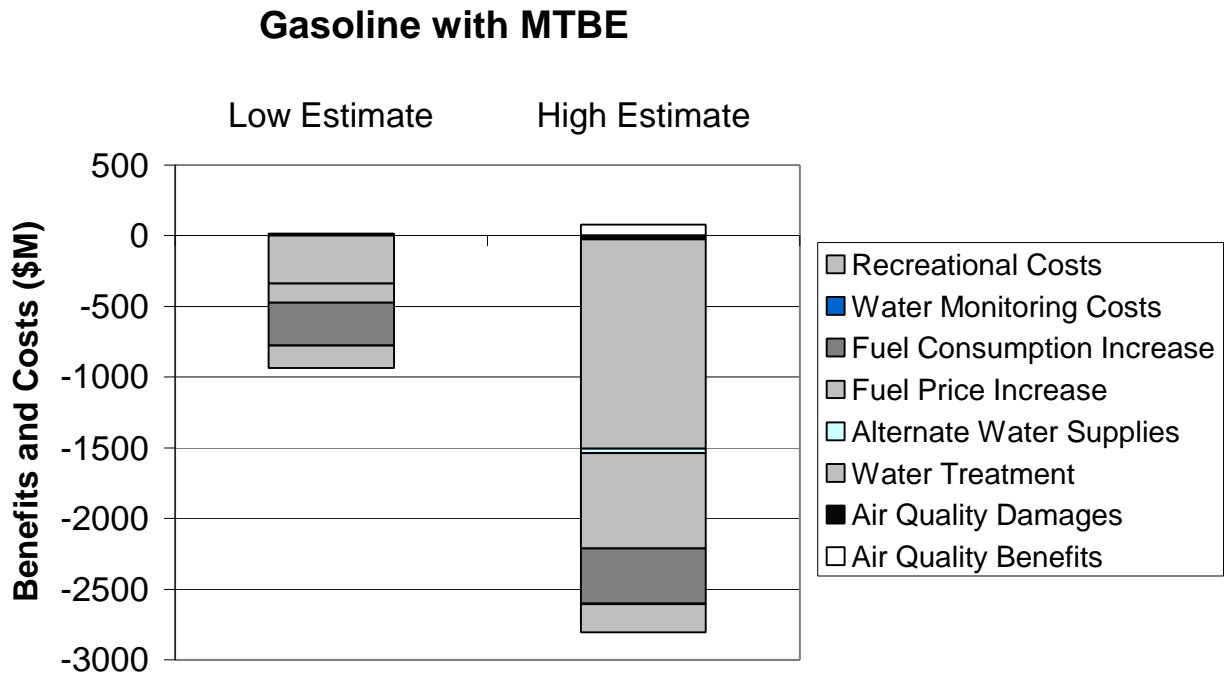


Figure 2. Cost and Benefits of Reformulated Gasoline with Ethanol

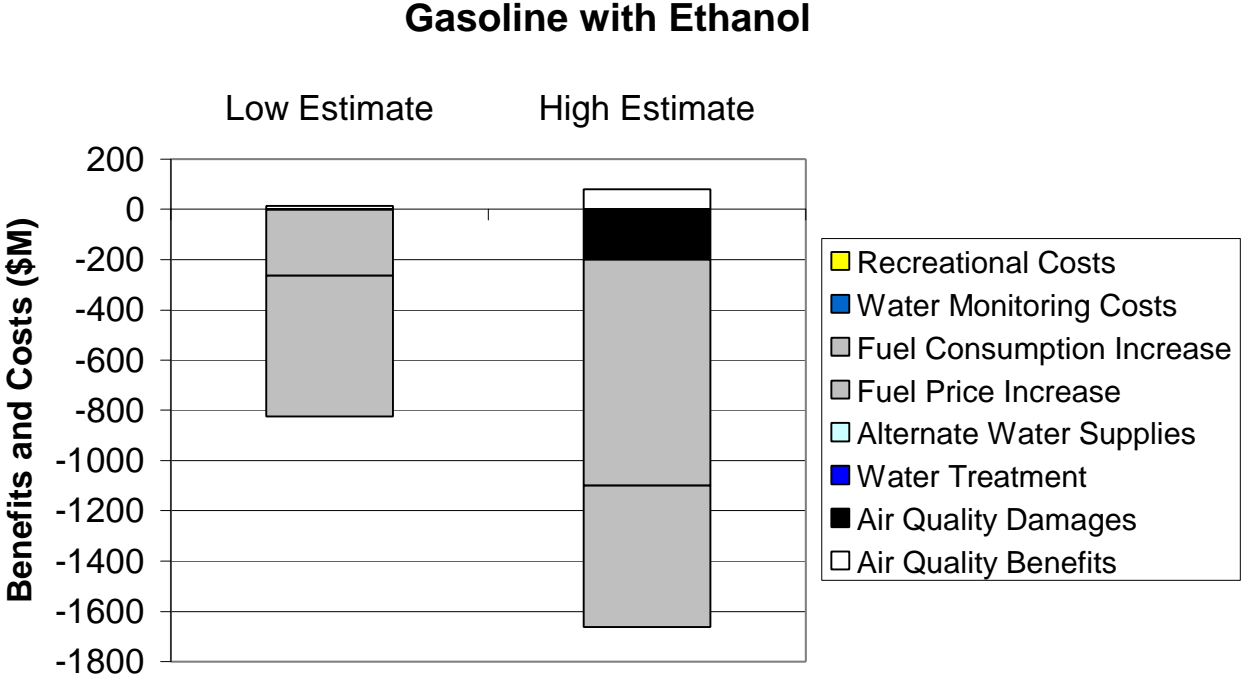


Figure 3. Cost and Benefits of Non-oxygenated Reformulated Gasoline

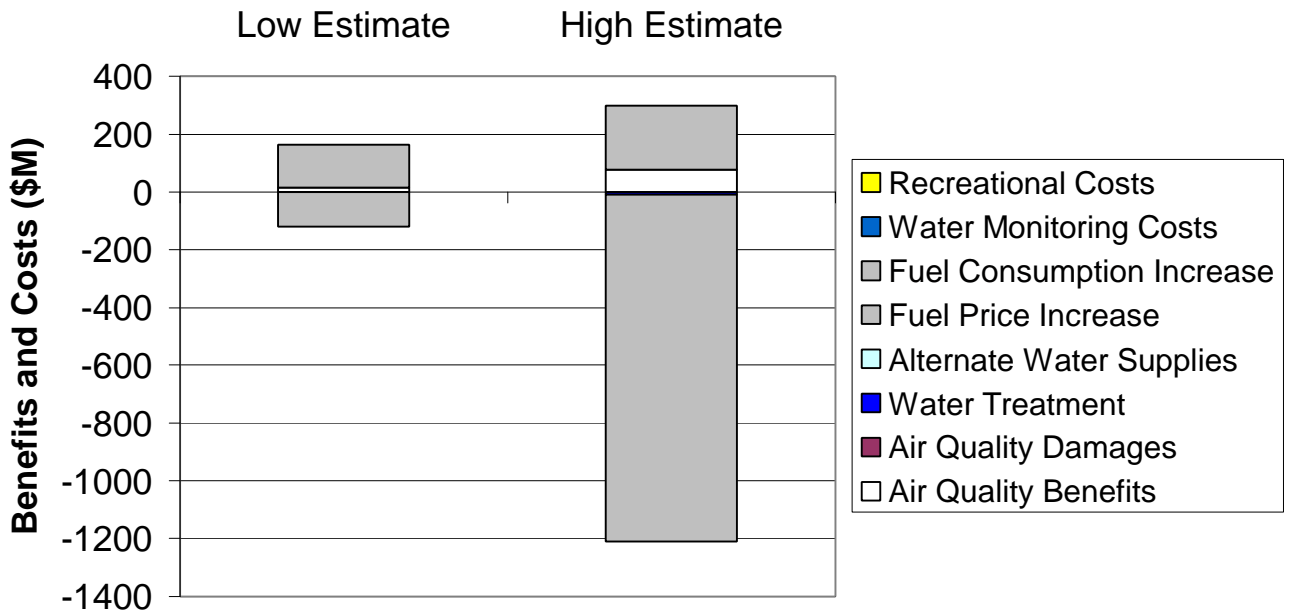


Figure 4. Net Benefits (Costs) of Gasoline Formulations

