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Beyond MTBE: Applying the Precautionary Principle to Gasoline Additives

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Based on an evaluation of the physicochemical and toxicological properties of Methyl tert-Butyl Ether (MTBE), as well as an ex post-facto cost and benefit analysis, it has become clear that there are less expensive and disruptive approaches to achieving the goals of the 1990 Clean Air Act Amendments with regards to gasoline-powered mobile sources. However, before jumping to the next blending component to improve combustion efficiency and reduce air emissions, we propose a thorough investigation of the properties of alternatives to MTBE, such as ethanol, toluene or alkylates. We conducted a preliminary cost/benefit analysis of the various alternative formulations based on the information available in California. We conclude that non-oxygenated reformulated gasoline presents the least cost for the same benefits. However, we should apply the Precautionary Principle and conduct an exhaustive research program to ensure that such widely used gasoline components are not persistent and that the toxicological or organoleptic properties are within acceptable bounds.

Introduction

It has often been said that if gasoline had recently been invented, it could not obtain approval for today's marketplace, given its toxicological properties. For most human beings, gasoline is one of the chemical mixtures to which they will most likely be exposed in significant amounts throughout their lifetimes. Since gasoline includes benzene and other aromatic compounds, it would be classified as a carcinogenic substance. In addition, given that the intended use is to combust gasoline for fuel, there would be significant concern with the known generation of hundreds of products of incomplete combustion, including aldehydes, carbon monoxide and many other potentially toxic organic compounds, as well as nitrogen oxides. After more than 100 years of use, gasoline continues to generate significant controversy, as the recent experience with Methyl tert-Butyl Ether (MTBE) indicates.

In addition to the toxicity of some gasoline components, the introduction of gasoline additives to improve the performance of the internal combustion engine continues to present challenges. Adding compounds to gasoline to improve performance dates back almost 80 years, starting with the introduction of tetraethyl lead (TEL) to gasoline to reduced engine "knock" by improving the octane rating. Despite the fact that as early as the 1920s public health experts, government officials and many other people were acutely aware of the dangers posed by the introduction of lead into gasoline (1,2), TEL was added for over 60 years in the US, and continues to be used in many countries around the world, for economic considerations. In the early 1970s, gasoline producers began to feel the pressure to find substitutes for TEL. Industry studies as early as the 1950s indicated that several ethers, including MTBE and Ethyl tert-Butyl Ether (ETBE), could improve the octane ratings of a gasoline mixture. Since MTBE could be produced from isobutylene, a refining byproduct, it was a logical choice. As TEL was phased out, MTBE began to be widely used at 2 to 3 % by volume.

Studies by the automobile and oil industry indicated that the use of these ethers could significantly improve the combustion of gasoline, reducing carbon monoxide emissions (3). Preliminary results from these studies led to the incorporation of an “oxygen-content” mandate in the 1990 Clean Air Act Amendments (CAAA), for reformulated gasoline sold in areas where air quality standards were not being met. A number of other specific requirements were imposed on the new gasoline formulations; rather than specify performance requirements, legislators decided to dictate the way gasoline should be produced. For the most part, gasoline producers decided to use MTBE, since it provided the required oxygen content, and was in general easier to blend with gasoline than ethanol. In addition, MTBE was cheaper than ethanol in most regions, and the supply was not dependent on agricultural prices and other issues concerning the ethanol market. In several mid-western states gasoline was blended with ethanol to produce "gasohol" and meet the oxygen content requirements.

At the time all these decisions were being made, the toxicological information on MTBE and other potential "oxygenates" was incomplete. The fate and transport data indicated that these compounds would be rather soluble in water, with little sorption, indicating that if any MTBE or other oxygenates leaked from Underground Storage Tanks (USTs), they could potentially travel far towards drinking water wells. Information on their natural rate of biodegradation was practically non-existent. One would assume that this would have led regulators to immediately start a major research effort to collect such data (toxicity and biodegradability), but since the main concern was air quality, potential impacts on water resources did not become prominent. Once again, economic considerations came first, without a full consideration of the entire life cycle of these oxygenates.

MTBE began to make headlines once prominent leaks in the City of Santa Monica, CA resulted in the shut down of several drinking water supply wells, with a potential liability to the responsible parties of millions of dollars (4). Once it became common place to include MTBE in the analysis of contamination around USTs as well as surface water reservoirs where motor boats are allowed, it became clear that MTBE contamination was much more widely spread than regulators had foreseen. In a very short time, MTBE began to be detected in hundreds and then thousands of wells around the US, wherever it had been used since the phase-out of TEL. California legislators passed California Senate Bill 521, which mandated a thorough review of the health and environmental impacts of MTBE in the state, to be conducted by the University of California. The report produced a truly interdisciplinary, multimedia evaluation of the impact of MTBE (5), including a cost-benefit analysis that clearly indicated that there were cheaper alternatives to obtain the air quality objectives of the 1990 CAAA (6). Based on these findings, Governor Gray Davis decided to phase out the use of MTBE in California over the next three years (7). USEPA has recently given "Advance Notice of Proposed Rulemaking to Control MTBE in Gasoline", which sends a clear signal about its position on MTBE (8).

Several alternative blending components have been identified for MTBE, including ethanol, toluene and alkylates (6,9-11). We are again at a crossroads where important decisions will be made on chemicals that will be widely used, and it would seem that the use of the precautionary principle is appropriate. This study thus presents a review of the most relevant considerations regarding these various gasoline formulations, and discusses the issues that should be evaluated *before* another costly mistake is made. We limit our scope to gasoline formulations, but clearly the precautionary principle could be applied more generally to the use of gasoline.

Precautionary Principle

The precautionary principle was first applied internationally in the context of marine pollution control, through the 1987 Declaration of the Third Ministerial Conference on the North Sea as "action to avoid potentially damaging impacts of substances that are persistent, toxic and liable to bioaccumulate" (12). Behind every major environmental policy decision there is an element of scientific uncertainty. The Bergen Declaration clearly states that policy making should not be postponed due to incomplete information when there is sufficient reason to believe that preventive action might diminish environmental impacts (13). Part of the preventive measures that should be taken immediately is a full cross-media assessment of environmental impacts, and a determination of scientific uncertainties. Research to reduce these uncertainties should be an integral component of any new legislation that involves substances that are persistent, toxic, can bioaccumulate and are produced in large quantities. Any substance added to gasoline in a significant amount should be fully characterized with respect to its persistence, toxicity and bioaccumulation, since it is a given that it will be produced and distributed in large amounts. Failure on any count should be a reason for searching for alternatives.

On practical terms, it is not feasible to demand that companies demonstrate that every substance is absolutely harmless. However, certain rules should be established based on sound scientific methods that relate chemical structure to activity (e.g. hydrophobicity, biodegradability, toxicity). Good science involves raising a yellow flag when it is probable that a new substance is likely to produce a bad outcome, and this should be followed through with an aggressive research effort to make sure that all the environmental impacts have been assessed. The increasing liability issues raised by these substances should lead firms to apply the Precautionary Principle as part of a "Best Management Practice".

In the next section, we present the results of our cost-benefit analysis for different gasoline formulations across all environmental media, which emphasizes the need to apply the Precautionary Principle for the next generation of gasoline blending components.

Analysis Costs and Benefits of Gasoline Formulations

The following study of the costs and benefits of three gasoline formulations that meet California's Phase II Reformulated Gasoline (CaRFG2) requirements was conducted in 1998, after CaRFG2 with MTBE had been in the California market for over two years. The study included CaRFG2 with ethanol and non-oxygenated CaRFG2. An important component of our analysis was to keep track of our uncertainties, and to make sure that the final answers (net cost or net benefit) reflected such uncertainty. Thus, if a proposed alternative results in a net cost, even when all the uncertainties are considered, the Precautionary Principle indicates that research to reduce the uncertainties should be started immediately, and the implementation of the alternative should be contingent on a new outcome (i.e. a net benefit).

The study was focused on California due to the funding source, but can be easily generalized to all those areas (US or around the world) where MTBE is being used or is under consideration. There will be some differences, given the diversity of opinions on the level at which water contaminated with MTBE should be treated (which has a major impact on the overall cost of treatment). In addition, the air quality benefits may differ, depending on the level of air pollution. In addition, the uncertainties regarding the prices of the various blending components (MTBE, ethanol, toluene, alkylates) will become greater in the short-term if many regions switch to these compounds. It should be noted that without having done a full analysis, clearly the substitution of TEL by MTBE has produced major health benefits around the world, although it is probable that the same benefits would have been realized with alternative formulations that did not adversely affect water quality.

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 CAAA. To simplify the analysis, we assume that each gasoline alternative is used 100% in California.

Air Quality Benefits

For the air quality benefits, we considered the reduction in benzene and other air toxics concentrations in the atmosphere, as well as the projected decrease in carbon monoxide and ozone concentrations from the cleaner burning reformulated gasoline. 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. To derive a value of air quality benefits associated with reduced morbidity effects from decreases in carbon monoxide and ozone we used the cost of illness approach which sums medical expenditures and lost wages associated with morbidity. The total value of benefits from avoiding morbidity due to carbon monoxide is the sum of hospital and restricted days avoided which equals $9.6 million. The total value of benefits from avoiding morbidity due to ozone is the sum of hospital days and restricted days avoided which equal $8.8 million. Ambient concentrations may vary widely, spatially and temporally, even within an air basin. To simplify our analysis, we assumed that the 1-hr average ozone concentration was uniformly distributed, which may result in an overestimate of the benefits, since a smaller subset of the population is experiencing the higher concentrations.We provide a detailed accounting of our calculations in (6) and (14).

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. Thus, the benefits of adding oxygenate to gasoline formulations are relatively small and decreasing with time and may result in health costs from combustion byproducts (e.g. formaldehyde).

Air Quality Costs

The combustion of MTBE results in a slight increase in the concentration of formaldehyde in the vehicle emissions, due to incomplete combustion (9,15). Combustion of ethanol produces increases in acetaldehyde (9). Both of these aldehydes are known carcinogens. While the air quality costs for MTBE may range from $0 to $27 million, the uncertainty in the magnitude of acetaldehyde emissions from ethanol combustion produces a cost estimate of $3 to $200 million. Since gasoline/ethanol formulations have been sold in the Midwestern USA and in Brazil for several years, it should be rather inexpensive to reduce the uncertainty in this cost estimate by collecting data at these locations.

Combustion of additional toluene or alkylates has not been shown to significantly increase the emissions of air toxics, but it should be pointed out that the studies have been limited and that additional work is needed to reduce the uncertainty in this respect.

Water Quality Costs

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 was estimated in 1998 to be on the order of $340 to $1,480 million per year, 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. If the UST technology and workmanship could deliver 100% leak proof tanks, the savings and reduced environmental impact would be considerable. The estimates on the number of tanks that have leaked gasoline with MTBE were obtained from (16) and (17). Unit water treatment costs were prepared based on experimental studies

(18). Groundwater remediation costs include the legacy of older leaking USTs in California 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, with a large uncertainty about the effectiveness of new upgraded tanks.

Since ethanol biodegrades fairly rapidly, it would appear that the cost of using ethanol, in terms of risk to the water supplies, is low. Recent studies (19,20) indicate that the rapid biodegradation of ethanol at the leading edge of a groundwater plume would deplete dissolved oxygen. This in turn will result in an extension of the BTEX plume of up to 30%, which might result in a larger number of BTEX plumes reaching drinking water wells. The organoleptic properties of water with low concentrations of ethanol have not been determined, and while some might not perceive ethanol at low concentrations, others might find it unacceptable in their drinking water supply. The uncertainty resulting from these considerations has not been included in our analysis, but should be a priority research area if ethanol is considered as an MTBE replacement.

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. Treatment technologies are well developed. 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 that translate to an annualized cost increase of $600,000 to $10 million.

Direct Costs

Blending MTBE, ethanol or other compounds with gasoline can result in increased costs. Blending MTBE with gasoline at 11% by volume results in an increase of 1 to 5 cents/gallon. The extra cost of using MTBE to meet CaRFG2 requirements, considering an annual consumption of 13.5 billion gallons, is $135 to $675 million. Although small, the price increase is significant.

The California Energy Commission has conducted a study of the supply and cost of gasoline alternatives to MTBE that includes ethanol (10). The estimated unit price increase ranges from 1.9 cents per gallon to 6.7 cents per gallon. 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 additional cost of producing a non-oxygenated gasoline is estimated to range from 0.9 to 8.8 cents/gallon or from $141 million to $1.3 billion per year (10).

Another component of the overall direct price is the effect of the blending components on fuel consumption. Gasoline consumption increases when oxygenates are added to conventional gasoline, due to a reduction in the energy content of the gasoline. The opposite occurs for the non-oxygenated gasoline formulations, where the energy content increases by about 0.8 to 1.2% depending on the amount of toluene or alkylate used.

A number of additional costs were identified in our analysis, including the damages to ecosystems, the economic cost of restricting motorboats at multi-use drinking water reservoirs, legal costs, etc. They are discussed in more detail in (11).

Summary of Costs and Benefits

Figure 1 presents the costs and benefits for the three formulations studied, indicating our high and low estimates for the costs and benefits, based on the uncertainties associated with the data. Costs (relative to the baseline, conventional gasoline) are presented in parenthesis. We have stacked up the costs and benefits, to provide a visual appreciation of the size of our cost estimates relative to the benefits. All the formulations represent a net cost (with the low estimate for non-oxygenated gasoline close to zero cost), with MTBE representing the most expensive option.

Conclusions

In hindsight, it is clear that reformulated gasoline with MTBE was an expensive solution to air quality problems. Spending 1 to 3 billion dollars a year in California alone certainly seems unjustified, once a thorough analysis of the costs and benefits is performed. The major uncertainties were the rate of biodegradation, the toxicity of MTBE and its organoleptic properties. It should have been more evident that a gasoline component used in such large quantities would make its way into the environment and cause more damages than benefits. The existing fate and transport data indicated that there was a possibility that such a gasoline component, used in large quantities would make its way into the environment, with the potential for causing more damages than benefits. The belief that the upgraded USTs would eliminate all spills was perhaps a factor in the decision-making process of oil companies. Granted, a decade ago not all the information needed to make this analysis was available, but the cost of such a research program would have been low, and could have been implemented and completed *before* the large scale introduction of MTBE. Remarkably, even today, there has been no coordinated effort by national or international authorities to reduce the uncertainties associated with MTBE.

We realize that some of the costs for CaRFG-MTBE overlap and therefore, the net costs represent an upper bound. For example, if water treatment costs are incurred to clean up water supply, the costs for alternative water supply will not incurred, except for the immediate supply of water prior to treatment being completed.

Our study considered MTBE replacements to begin the process of evaluating options before another fiasco occurs. It would be unacceptable to find out in a few years from now that we have a new problem with ethanol, toluene or alkylates. We have evaluated the existing information, and in our opinion the non-oxygenated option appears to create less risks than MTBE or ethanol. There are some clear benefits of using ethanol, since it is a renewable resource. The use of ethanol produced from biomass would also reduce carbon dioxide emissions, a major greenhouse gas. However, the potential air quality damages need to be assessed, and the effect on the price of gasoline should be considered relative to other alternatives. We should also begin to consider the source of all this biomass. If we can use current agricultural waste products (e.g. corn stalks, rice straw), then this will be a beneficial shift in the source of our fuel supply. But if it requires significant deforestation around the world to produce enough ethanol for US or worldwide demand, then other options should be explored.

Thus the need to apply the Precautionary Principle to any gasoline blending component, and insist on a thorough evaluation of the implications of such a decision. We must be much more certain of the toxicity, persistence and bioaccumulation of gasoline blending components, since it is a given that these chemicals will be used in large amounts throughout the world. Let’s not make the same mistake again.

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Figure 1. Annualized Cost and Benefit Analysis of Gasoline Formulations in California