The Social Costs of an MTBE Ban in California -

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In the early 1990s, oxygenated gasoline was widely hailed as a solution to many of the nation's air quality problems. Even though the anticipated air quality benefits of oxygenated gasoline were in fact realized, the large-scale use of methyl tertiary butyl ether (MTBE) as a gasoline oxygenate resulted in adverse impacts to water quality. The use of MTBE exposed in dramatic fashion the fundamental problem of leaking underground storage tanks. As MTBE was detected in water supplies in the late 1990s, public concern intensified and proposals to ban the use of MTBE in gasoline surfaced in several states, most notably in California, which moved to ban the use of MTBE in gasoline by the end of 2003. As of December 31, 2003, California refiners no longer blend MTBE into gasoline.[1]

While the widespread use of MTBE has had adverse impacts on water quality, removal of MTBE from gasoline will impose significant costs on society—in terms of both gasoline production costs and prices and possible impacts on air and water quality by fuel blending components that replace MTBE in gasoline. In moving to protect groundwater resources from MTBE, California may force the adoption of gasoline formulations that are, in fact, less beneficial to society. Unfortunately, the total social cost of banning MTBE has not been properly evaluated by the studies that have been conducted to date.

This analysis provides a comprehensive and internally consistent cost-benefit framework of gasoline formulation alternatives for California. It includes several categories of cost that have largely been neglected in past analyses of MTBE use. These include (1) the cost to taxpayers of increased ethanol consumption due to the ethanol tax subsidy; (2) increases in the cost of oil imports caused by replacing MTBE volumes with blending components made from other substitutes; (3) the effects of changes in gasoline prices on gasoline consumption and thus on automobile emissions; and (4) the potential effect of MTBE substitutes such as ethanol on water quality.

Overall, the analysis indicates that continued use of MTBE in California gasoline would have had clear and significant benefits relative to the use of either ethanol or non-oxygenated reformulated gasoline. The increased annual cost resulting from banning MTBE in California when ethanol replaces MTBE ranges from $0.34 to $1.01 billion with an expected value of $0.86 billion. If non-oxygenated reformulated gasoline were chosen to replace MTBE, the annual increased cost would range from $0.39 to $1.05 billion with an expected value of $0.88 billion. The model results are robust to reasonable ranges of uncertainty; even under the worst case for MTBE and the best case for the other substitutes, it still follows that banning MTBE will lead to an increase in the total cost of gasoline in California.

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[1]   California Energy Commission, quarterly report concerning MTBE in gasoline, October 1–December 31, 2003. Staff Report issued February, 2004.

1. INTRODUCTION

In the early 1990s, oxygenated gasoline was widely hailed as a solution to many of the nation's air quality problems, especially in so-called "federal nonattainment areas." At that time, it was expected that MTBE (methyl tertiary butyl ether) would be widely used as a gasoline oxygenate. Even though the anticipated benefits to air quality from oxygenated gasoline were in fact realized, large-scale use of MTBE as a gasoline oxygenate resulted in adverse impacts on water quality. As MTBE was detected in water supplies in the late 1990s, public concern intensified and proposals to ban the use of MTBE in gasoline surfaced in several states.

In 1999, California passed the first legislation in the United States that was motivated by the water quality impacts of MTBE. Under the authority granted by this legislation, the governor of California announced in March 1999 that MTBE would be banned in gasoline in the state beginning in 2003.[2] Several other states have moved to reduce or eliminate use of MTBE as well, and the U.S. Environmental Protection Agency (EPA) is evaluating a federal ban.[3] On March 15, 2002, the governor issued a new executive order and announced a one-year extension to the phase-out of MTBE. "Under the newly announced timeline, the MTBE phaseout will be accomplished no later than December 31, 2003. Individual refineries may continue to make the transition to ethanol earlier than December 2003 if they determine it is feasible and will not risk supply shortages or price spikes."[4]

At the same time that it moved to ban MTBE, California also requested that the EPA waive the federal minimum oxygenate requirement for reformulated gasoline (RFG) sold in California. While this request has been denied,[5] California congressional representatives have introduced legislation that would waive the federal oxygenate requirement, allowing California and the rest of the United States to produce and sell non-oxygenated gasoline. Although these waivers have not been enacted, the deadline for the MTBE ban was met and as of December 31, 2003, California refiners had completely phased out the blending of MTBE in gasoline.[6]

The purpose of this report is to provide a comprehensive and internally consistent cost-benefit analysis of the gasoline formulation alternatives for California. Its secondary purpose is to provide an analysis that may be useful to other states considering similar bans. Such an analysis must distinguish between sunk and incremental costs[7] and must consider both private and social costs.[8] The analysis must also take into account the economic responses of consumers and firms to

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[2] Governor Gray Davis, Executive Order D-5-99, 1999a.

[3] Governor Gray Davis, letter to Carol Browner, 1999b.

[4] California Energy Commission, quarterly report concerning MTBE in gasoline, October 1–December 31, 2003. Staff Report issued February, 2004.

[5] Christine Todd Whitman, Administrator, Environmental Protection Agency, Letter to Gray Davis 2001.

[6] California Energy Commission, quarterly report concerning MTBE in gasoline, October 1–December 31, 2003. Staff report issued February, 2004.

[7] *Sunk costs* are those costs that cannot be averted by future action. For instance, *past* use of MTBE may result in *current* sites of groundwater contamination that will result in *future* remediation costs. However, even if MTBE is removed from gasoline now, this would not affect the past, current, and future costs of *existing* contamination sites. Therefore, these remediation costs are not a cost of continuing to use MTBE in gasoline. Only those remediation costs from *future release*s of gasoline containing MTBE are a cost of the continued use of MTBE.

[8] *Private costs* are costs reflected in market prices of products. The most obvious example is a change in gasoline prices faced by consumers. Private costs should also account for effects in related markets such as natural gas. Other private costs are less obvious impacts on the effective price of gasoline to consumers, such as changes attributable to replacing MTBE with other blending components on the amount of gasoline required to drive a mile. *Social costs* are costs not necessarily included in market prices or considered by consumers and producers in decisions about how much to buy and sell. The impacts of MTBE on water resources and of changes in air quality (and thus on human health) are examples of social costs. Prior studies have assumed, correctly, that the performance requirements for RFG stated in terms of required reductions in emissions of ozone precursors—nitrogen oxides and reactive hydrocarbons—and carbon monoxide would not be compromised by a ban on MTBE. However, there are differences in the emissions of some air toxics and potential carcinogens among gasoline alternatives, and these differences need to be carefully considered.

changes in prices and costs and must consider not only costs in the immediate market in question but also costs from spillovers to other markets.

Several categories of cost that are important to any comprehensive cost-benefit analysis have not been included in the existing literature. These costs include (1) the cost to taxpayers of increased ethanol consumption due to the ethanol tax subsidy; (2) the net increase in the cost of oil and natural gas imports caused by replacing MTBE volumes with blending components made from other substitutes; (3) the effects of changes in gasoline prices on gasoline consumption and in turn on automobile emissions; and (4) the potential effect of MTBE substitutes such as ethanol on water quality.

It is also critical to recognize that the incremental costs and benefits of removing MTBE from gasoline change with the passage of time. The use of oxygenated gasoline in the early 1990s was intended to provide rapid reductions in emissions from the existing fleet of vehicles—reductions that could not be achieved through new-car emission standards alone. But as vehicles subject to new, much more stringent emission standards have become a larger share of the fleet, the air quality benefits attributable to the use of oxygenated gasoline have declined. Moreover, new air quality models adopted by the California Air Resources Board (CARB) (part of California's Environmental Protection Agency) for evaluating emissions reductions from RFG may also significantly change the estimated air quality impacts of various fuel formulations. The costs of replacing MTBE are also different today than they were a decade ago. The U.S. Supreme Court recently upheld a Unocal patent that covers many of the most cost-effective formulas for producing RFG, and this patent will raise costs for other refiners and consumers. Effects on water supply and cleanup costs attributable to future MTBE use are also certainly different today than they were ten years ago. For instance, older underground gasoline storage tanks that were prone to leaks have nearly all been replaced by new tanks that are much less likely to leak.

Before turning to the cost-benefit analysis presented in Section 4, it is useful to review the regulatory history and current environment pertaining to MTBE and current feasible alternatives to it. Section 2 addresses the regulatory environment affecting gasoline formulation in California. This environment includes federal regulations, State of California regulations, a California request for a waiver of the gasoline-oxygenate requirement of the Clean Air Act Amendments (CAAA), recent U.S. EPA rulemaking regarding MTBE, a pending North American Free Trade Agreement (NAFTA) arbitration, and pending legislation that has been introduced in the U.S. Congress. Section 3 then discusses alternative gasoline formulations and the relevant options that are available under an MTBE ban. The cost-benefit analysis is presented in Section 4. Section 5 presents concluding remarks.

2. FEDERAL AND CALIFORNIA REGULATIONS AFFECTING GASOLINE

Under current law, all gasoline sold in "ozone non-attainment areas" of California is subject to the federal RFG program and must contain a minimum of 2.0 percent oxygen by weight. This requirement can be satisfied by a blend that contains either 5.7 percent ethanol or 11.5 percent MTBE (by volume). In addition, gasoline sold during winter months in "carbon monoxide nonattainment areas" of California is subject to the federal oxygenated fuel requirement and must contain at least 1.8 percent oxygen by weight.

California is authorized under *42 USC Section 7545(c)(4)(B)* to craft its own controls on motor vehicle emissions and fuels as long as they are at least as stringent as the national standards. Under this authority, CARB established rules for cleaner-burning gasoline in California that are more stringent than the federal standards except in the area of oxygenates. The federal RFG requirements pre-empt California RFG requirements because they set a more stringent standard for oxygenates than do the California regulations.

The original version of the California RFG rule required a minimum of 1.8 percent oxygen in winter throughout the state, but that rule was revised in 1998 to apply only to areas subject to federal winter oxygen requirements. CARB recently issued Phase 3 RFG regulations that would allow refiners throughout the state to sell non-oxygenated gasoline even in federal RFG areas if a waiver of the federal requirement is granted. That waiver request was denied in June 2001.

2.1 Federal Reformulated Gasoline

The federal RFG program was created by the CAAA. Its purpose was in large part to reduce emissions of so-called ozone precursors, particularly hydrocarbons (referred to in the act as volatile organic compounds or VOCs) from the existing fleet of vehicles. In addition, the CAAA set limits on benzene and heavy metals and required EPA to ensure that nitrogen oxide emissions

not be allowed to increase. The requirement for use of RFG applies in areas of the country that have not attained the Ozone National Ambient Air Quality Standard. Initially, the nine worst ozone nonattainment areas in the nation, including Los Angeles, were subject to the requirement. The requirement also applies to an area one year after it has been reclassified as a "severe ozone nonattainment area," which led to Sacramento being included in 1998.

The CAAA set up a performance requirement for the federal RFG program. This regulation required the EPA's rules to achieve a specified reduction in emissions relative to a baseline gasoline defined by the act. The performance standards were enacted in two "phases." The Phase 1 standard was a 15 percent reduction in hydrocarbon emissions on a mass basis. Beginning in 2000, the Phase 2 standard required a 25.9 percent reduction in hydrocarbons in northern areas and a 27.5 percent reduction in southern areas, as measured against the baseline gasoline.

In addition to the performance standard, the CAAA stated that RFG must contain oxygenates to provide at least 2.0 percent oxygen by weight in the fuel. To meet the oxygenate requirements, refiners are permitted to blend into gasoline any of a number of oxygenates, including MTBE, ethanol, ethyl tertiary butyl ether (ETBE), or tertiary amyl methyl ether (TAME).[9] Except for ethanol, all of these oxygenates are ethers. MTBE had already been used in small quantities for a number of years to boost the octane in gasoline and served primarily as a replacement for lead. Following passage of the CAAA, MTBE became the preferred blending component in California (and other states outside the Midwest) for meeting the minimum oxygen requirement in RFG.

Carbon monoxide (CO) nonattainment areas are required under separate provisions of the federal CAAA of 1990 to sell oxygenated gasoline during certain winter months. In California, only the South

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[9]   Since ethanol contains approximately 35 percent oxygen by weight, a blend that contains 5.7 percent ethanol meets the federal requirement. MTBE contains approximately half as much oxygen as ethanol, 17 percent by weight, so the blend must contain approximately 11 percent MTBE to meet the federal standard.

Table 1. Federally Reformulated Gasoline Areas in California

Los Angeles

– South Coast Air Basin, South East Desert, Ventura

– Los Angeles County

– Ventura County

– Orange County

– San Bernardino County (partial)

– Riverside County (partial)

San Diego

– San Diego County

Sacramento* (newly required area)

– El Dorado County (partial)

– Placer County (partial)

– Sacramento County

– Solano County (partial)

– Sutter County (partial)

– Yolo County

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* Reclassification of Sacramento from *Serious* to *Severe* was effective June 1, 1995. RFG was required as of June 1, 1996.

Coast Air Basin and part of Imperial County are now subject to federal winter oxygenate requirements.

Table 1 lists the counties in California where federal RFG rules currently apply. Since these counties contain a large share of the state's population, CARB estimates that 70 percent of the gasoline currently sold in California is subject to the federal RFG regulations, including the minimum 2 percent oxygen requirement.[10] Without a change in the CAAA or a waiver of the application of current federal rules to California, it would be illegal to sell a "non-oxygenated CARB gasoline" within these designated ozone nonattainment areas, even if it met all the other specifications of the CARB standards.

2.2 California Cleaner Burning Gasoline

California is authorized under *42 USC Section 7545(c)(4)(B)* to set standards for motor vehicle emissions and fuels as long as the California standards are at least as stringent as the national standards. CARB is authorized under state law to establish motor vehicle fuel specifications.[11] Under this authority, California has its own RFG regulations.[12]

CARB adopted its Phase 2 RFG regulations in November 1991 and set March 1, 1996, as the date when these regulations would take effect.[13] The Phase 2 regulations defined a reference fuel and required that any gasoline sold in California have emissions of three specified pollutants that are at least as low as those of the reference fuel. The three specified pollutants are hydrocarbons (HC), nitrogen oxides (NOx), and potency-weighted toxics (PWT). The specifications of the reference fuel include regulations for eight properties but do not explicitly require that an oxygenate be used to meet the standards.[14] However, until 1998, CARB regulations required a statewide 1.8 percent

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[10] Gomez et al., *Staff Report: Initial Statement of Reasons for Proposed Rulemaking*, 1998.

[11] *California Health and Safety Code*, Sections 43013 and 43018.

[12] "California has unique status under Section 211(c)(4)(B) of the Clean Air Act. Because its air pollution program predated the federal program and because air quality in portions of the state is worse than that anywhere else in the country, California is allowed to have separate regulations for fuels. Thus gasoline sold in portions of the state (Los Angeles, Sacramento, and San Diego) must meet two separate sets of requirements—state and federal. The federal requirements . . . mandate that RFG contain at least 2 percent oxygen by weight (a requirement now generally met by adding MTBE to the fuel)." These standards apply in areas containing about two-thirds of the state's population. "California's standards, which became effective a year later than the federal, include an oxygen content specification 'because of the oxygen requirements in the federal RFG program.' According to the Cal EPA, however, 'a key element of the California program is a mathematical or 'predictive' model that allows refiners to vary the composition of their gasoline as long as they achieve equivalent emission reductions. . . . For areas not subject to federal requirements, refiners can use the predictive model to reduce or even eliminate the use of oxygenates,' except during the four winter months, when they are subject to separate oxygenate requirements to reduce carbon monoxide." McCarthy and Tiemann, *MTBE in Gasoline: Clean Air and Drinking Water Issues*, 1998.

[13] See CARB, *The California Reformulated Gasoline Regulations, Title 13, California Code of Regulations, Sections 2250–2273*, 2000.

[14] The eight properties are Reid vapor pressure (RVP), sulfur, benzene, aromatics, olefins, oxygen, T50, and T90. T50 and T90 are the temperatures at which 50 percent and 90 percent (respectively) of the gasoline boils off.

minimum oxygenate content in winter as part of the California State Implementation Plan (SIP).[15] In 1998, CARB replaced the statewide minimum winter oxygenate requirement with a winter oxygenate requirement applicable just to the CO nonattainment areas. Thus, for gasoline sold outside these areas, CARB regulations do not require any minimum oxygen content (although the federal RFG regulations—and the attendant oxygenate requirement—still apply in ozone nonattainment areas).

CARB also developed a predictive model to be used by refiners to determine if a particular gasoline blend would produce emissions of the three regulated pollutants that were at least as low as those for the reference fuel. Development of the predictive model began in 1991, and it was adopted by regulation at a hearing in June 1994. California Phase 2 RFG production began on March 1, 1996. Seven of the eight Phase 2 gasoline properties can be varied according to the model. Only the Reid vapor pressure or RVP (a measurement of a gasoline's propensity to evaporate) value is fixed at 7.0.[16] The predictive model performs a number of calculations to predict emissions of HC, NOx, and PWT from the candidate fuel and compares the emissions to those predicted for the reference fuel to determine if the candidate fuel is acceptable. Caps are also placed on specific fuel properties, and the fuel blend must satisfy both these caps and the emissions requirements. The refiner can choose to meet the alternative specification for every gallon produced (flat limit) or to meet the specification on average (averaging limit). The averaging limits were chosen to represent what CARB believed would be the observed average

specifications if a number of samples were taken of gasoline produced to meet the flat limit.[17]

In 1997, the University of California conducted a health and environmental assessment of MTBE for the State of California. The report, issued in November 1998, recommended a gradual phase-out of MTBE-oxygenated gasoline in California. Legislation signed October 8, 1997, required the state to set standards for MTBE in drinking water. Based on this report and on public hearings, Governor Davis issued a finding in March 1999 that "on balance, there is a significant risk to the environment from using MTBE in gasoline in California."[18] Under authority granted by the 1997 legislation, Governor Davis ordered the California Energy Commission (CEC) to develop a timetable for removal of MTBE from gasoline at the earliest possible date, though not later than December 31, 2002. Following California's decision to phase out MTBE, a number of other states (including Iowa, Arizona, Colorado, New York, Connecticut, Michigan, and Minnesota) also acted to limit or phase out the use of MTBE. The largest of these, New York, planned to ban MTBE effective January 1, 2004. In addition, Maine opted out of the RFG program in October 1998 as a result of concerns over MTBE.[19]

Governor Davis also directed CARB to adopt gasoline regulations to facilitate the removal of MTBE without reducing the emissions benefits of the existing program. The Phase 3 California RFG (CaRFG3) regulations, which banned MTBE after December 31, 2002, were approved on August 3, 2000. In March of 2002, the effective date of the ban was extended one year to January 1, 2004, by Executive Order D-52-02

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[15] See CARB, *Legal and Air Quality Issues in Removing Minimum Wintertime Oxygen Requirement*, 1998.

[16] CARB, *California Procedures for Evaluating Alternative Specifications for Phase 2 Reformulated Gasoline Using the California Predictive Model*, 1995.

[17] Under the flat limit, a refiner could produce gasoline with predicted emissions lower than those predicted for the reference fuel, but no gallon could have higher emissions than predicted for the reference fuel. Since there would be some natural variability from one sample to another, but no gallon could exceed the flat limit, the average of a number of samples satisfying the flat limit would have to be below the flat limit. In other words, in order to make sure that no gallon exceeded the flat limit, a refiner would have to aim for an average below the flat limit.

[18] Davis, Executive Order D-5-99, March 1999a.

[19] Areas not subject to the mandatory requirements of the federal RFG program were allowed under the CAAA to "opt in" to the program and require use of the federal RFG standard (*40 CFR 80.70(j)(10)(vi)*). During development of the RFG regulations, a number of areas expressed their intention to do so. Later, some of these areas requested permission to "opt out," provoking considerable controversy among refiners who had made investments to supply those areas with RFG.

of Governor Davis.[20] Table 2 lists the eight properties regulated by the California Phase 3 RFG regulations, the values of these properties in the new reference fuel, and the caps placed on these properties.

CARB developed a new version of the predictive model to support the Phase 3 program and has made preliminary versions of the model available. This study evaluated emissions from alternatives to MTBE using the proposed Phase 3 predictive model since it is more representative of the rules that will govern future gasoline supplies than is the Phase 2 predictive model.

The Phase 3 model makes a number of changes from Phase 2. It treats evaporative emissions of hydrocarbons and benzene differently. It also contains an updated description of the vehicle fleet that takes into account the more stringent emission controls on new vehicles that had entered the fleet since the Phase 2 model was developed. As a result, the Phase 3 model shows considerably smaller emission reductions attributable to RFG than the Phase 2 model does. The Phase 3 model contains no minimum oxygen requirement, but it does provide credit for the specific emission-reducing properties of oxygenates. Therefore, removing oxygenates requires compensation by increasing the use of some other beneficial component. The Phase 3 model also incorporates an RVP credit for ethanol as provided in federal and CARB regulations for reasons explained later.

Table 2. Properties and Specifications for Phase 3 Reformulated Gasoline -

Fuel Property	Units	Flat Limit	Averaging Limit	Cap Limit
Reid Vapor Pressure (RVP)	pounds per square inch, maximum	6.90 / 7.00[1]	none	7.2[1]
Sulfur (SUL)	parts per million weight, maximum	20	15	60 / 30[2]
Benzene (BENZ)	volume percent, maximum	0.80 / 1.00	0.7	1.10
Aromatic HC (AROM)	volume percent, maximum	25.0 / 35.0[3]	22.0	35.0
Olefin (OLEF)	volume percent, maximum	6.0	4.0	10.0
Oxygen (OXY)	weight percent	1.8 (min.) 2.2 (max.)	none	1.8 (min.)[4] 3.5 (max.)[5]
Temperature at 50 percent distilled (T50)	degrees F, maximum	213 / 220[2]	203	220
Temperature at 90 percent distilled (T90)	degrees F, maximum	305 / 312[2]	295	330

[1] The 6.90 pound-per-square-inch (psi) flat limit applies only when a producer or importer is using the evaporative-emissions-model element of the CaRFG3 predictive model, in which case all predictions for evaporative emissions increases or decreases made using the evaporative-emissions model are made relative to 6.90 psi and the gasoline may not exceed the maximum RVP cap limit of 7.2 psi. Where the evaporative-emissions-model element of the CaRFG3 predictive model is not used, the RVP of gasoline sold or supplied from the production or import facility may not exceed 7.0 psi.

[2] The CaRFG3 sulfur content cap limits of 60 and 30 ppm are phased in starting December 31, 2003, and December 31, 2005, respectively, in accordance with section 2261(b)(1)(A).

[3] For sales, supplies, or offers of California gasoline downstream of the production or import facility starting on the date on which early compliance with the CaRFG3 standards is permitted by the executive officer under section 2261(b)(3), the Phase 2 cap limits for RVP and aromatics content are 7.20 psi and 35.0 percent by volume, respectively.

[4] The 1.8 percent by weight minimum oxygen content cap only applies during specified winter months in the areas identified in section 2262.5(a) of the Phase 2 regulations.

[5] If the gasoline contains more than 3.5 percent oxygen by weight but no more than 10 volume percent ethanol, the maximum oxygen content cap is 3.7 percent by weight.

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[20] Davis, Executive Order D-52-02, March 2002.

2.3 California's Waiver Request

While California could (and did) change CARB's RFG regulations to no longer require the use of an oxygenate, the federal RFG regulations still required oxygenates in the gasoline sold in approximately 70 percent of the state where the federal RFG program applies. Thus, without a change in federal RFG regulations, removal of MTBE from all California gasoline would require the use of another fuel oxygenate. Under this circumstance, the only feasible alternative oxygenate to MTBE is ethanol.[21]

The replacement of MTBE with ethanol in California is widely predicted to be very costly.[22] Moreover, it is anticipated that widespread use of ethanol may also entail adverse consequences for the environment.[23] Adverse environmental impacts include increases in smog, increases in other toxic compounds in gasoline (such as sulfur and benzene), and impacts on groundwater quality.[24] Therefore, at the same time that Governor Davis moved to ban the use of MTBE, California requested that the EPA waive the federal minimum oxygenate requirement for RFG sold in California. With the waiver, it would be possible to satisfy the CARB regulations without using ethanol by producing a non-oxygenated gasoline as long as it met the requirements of the new Phase 3 predictive model.

The waiver request produced considerable controversy. According to the Corn Refiners Association (CRA), "The Clean Air Act authorizes waiver of the RFG oxygenate requirement only if the Administrator determines that oxygenates would prevent or interfere with the attainment of a National Ambient Air Quality Standard." The waiver request was supported by states, environmental interests, and many refiners. It was opposed by a number of parties, many of whom had economic interests in the production of ethanol, because completely eliminating the oxygenate requirement from the waiver would open the way for use of a non-oxygenated fuel throughout California and thereby limit the market for ethanol. California's request for a waiver was denied by the EPA, which concluded that there was no clear evidence that the use of non-oxygenated RFG would improve air quality relative to the use of RFG that used ethanol as an oxygenate.[25]

2.4 EPA Rulemaking on MTBE

In a related regulatory development, EPA announced on March 20, 2000, that it would start a regulatory

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[21] Other oxygenates such as ETBE and TAME exist. However, these products are ethers like MTBE and are expected to have water quality impacts similar to those of MTBE. Moreover, there is an insufficient quantity of these products available to meet the demand for all RFG in California. The Phase 3 CARB regulations also discourage the use of other ethers, thereby effectively requiring that MTBE be replaced by ethanol.

[22] California Energy Commission, *Staff Report: Supply and Cost of Alternatives to MTBE in Gasoline*, 1999a; MathPro, *Potential Economic Benefits of the Feinstein-Bilbray Bill*, 1999b (an analysis conducted for Chevron Products Company and Tosco Corporation). See also Youn, "Ethanol: California Needs It, But Can It Get It?" 2001; Card, Statement before the Committee on Energy and Natural Resources, U.S. Senate, 2001; *CNNMoney*, "California Faces Gas Shortage: Switch to Ethanol as Clean-Air Additive Seen Limiting Gasoline Supplies," 2001.

[23] "A key blending characteristic of ethanol is that when it is used as an oxygenate in gasoline, it significantly raises the gasoline's Reid Vapor Pressure (RVP), a measurement of the propensity of the gasoline to evaporate. Adding between 5 and 10 percent ethanol to gasoline (resulting in oxygen contents between about 1.9 and 3.5 weight percent oxygen) will increase the RVP of the gasoline by about 1 pound per square inch (psi); the increase with MTBE is only about 0.1 psi. This means that in the summertime high-ozone RVP control period (which stretches from March 1 through October 31 in the greater Los Angeles area), refiners using ethanol to satisfy the federal RFG oxygen mandate will have to make a blended gasoline having an RVP about 1 psi lower than the applicable standard. The federal RFG regulations do not provide a special RVP allowance for gasoline containing ethanol. In California, the ARB recently eliminated an RVP waiver for gasoline containing 10 percent ethanol because it found that the ozone benefits associated with the exhaust emissions from elevated-RVP gasoline are overwhelmed by the increase in ozone-forming potential from the increased evaporative emissions." California Environmental Protection Agency, *Basis for Waiver of the Federal Reformulated Gasoline Requirement for Year-Round Oxygenated Gasoline in California*, 1999; CARB, *Air Quality Impacts of the Use of Ethanol in California Reformulated Gasoline*, 1999b.

[24] *Reuters*, "Environmental Impact of Ethanol Fuels Debate," 2001; Card, statement before the Committee on Energy and Natural Resources, U.S. Senate, 2001.

[25] U.S. EPA, "Technical Support Document: Analysis of California's Request for Waiver of the Reformulated Gasoline Oxygen Content Requirement for California Covered Areas," 2001a.

process "aimed at phasing out MTBE" using Section 6 of the Toxic Substances Control Act (TSCA). According to the agency's press release:

> *Section 6 of the Toxic Substances Control Act gives EPA authority to ban, phase out, limit or control the manufacture of any chemical substance deemed to pose an unreasonable risk to the public or the environment. EPA expects to issue a full proposal to ban or phase down MTBE within six months, after which more time is required by the law for analysis and public comment before a final action can be taken.*

As the EPA noted elsewhere in its press release, a TSCA rulemaking is procedurally burdensome and may take "several years" to complete. The General Accounting Office noted that "To use the authority, the Agency will have to conclude that MTBE poses an unreasonable risk to health or the environment. In the 24 years since TSCA was enacted, the Agency has successfully invoked this authority against fewer than half a dozen classes of chemicals." The first step in this process was issuance of an Advance Notice of Proposed Rulemaking (ANPRM) on March 24, 2000.

2.5 NAFTA Arbitration

A new MTBE issue emerged in the wake of California's decision to phase out the use of MTBE in gasoline. On June 15, 1999, the Methanex Corporation, a Canadian company that produces methanol in the United States and Canada, notified the U.S. Department of State of its intent to institute an arbitration against the United States under the investor-state dispute provisions of NAFTA, claiming that the phase-out of MTBE ordered by the Governor of California on March 25, 1999, breached U.S. NAFTA obligations regarding fair and equitable treatment and expropriation of investments, entitling the company to recover damages, which it estimated at $970 million.[26] Should Methanex prevail in this arbitration, the costs of an MTBE ban may increase. However, this analysis does not include any monetization of those potential costs.

2.6 Pending Legislation

A number of bills have been introduced in the U.S. Congress that would either exempt California from the federal minimum oxygen standard or give states the right to waive the standard on their own initiative. Without such a change, it would be illegal to sell a "non-oxygenated CARB gasoline" within designated ozone nonattainment areas. Many of these bills would also extend the California MTBE ban to the rest of the country. Members of Congress from California have introduced a number of these bills, but a large number were co-sponsored or introduced by members from other states.

In a comprehensive report on current legislation issued in January 2001, the Congressional Research Service gave the following summary.[27]

> *Legislation that could affect MTBE use has been introduced in every Congress since the 104th. In the 106th Congress, a bill to ban the use of MTBE in gasoline within 4 years, allow states to waive the RFG program's oxygenate requirement, stimulate the use of ethanol and clean vehicles, provide additional funding for the cleanup of contaminated ground water, and provide additional authority to EPA to regulate fuel additives and emissions, was reported by the Environment and Public Works Committee September 28, 2000 (S. Rept. 106-426). On August 4, 1999, the Senate also adopted an amendment to the FY2000 agricultural appropriations bill (S. 1233), offered by Senator Boxer, expressing the sense of the Senate that use of MTBE should be phased out.*
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> *In addition to the reported bill, about 25 other bills related to MTBE were introduced in the 106th Congress. About half would have repealed the RFG program's oxygenate requirement or allowed waivers. Most would have phased out or limited the use of MTBE in gasoline.*

Supporters of these bills cite a report by the EPA's Blue Ribbon Panel on Oxygenates in Gasoline that

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[26] Methanex Corporation, "Methanex Corporation, Claimant/Investor, and The United States of America, Respondent/Party, Claimant Methanex Corporation's Draft Amended Claim," submitted to U.S. Department of State, 2001.

[27] McCarthy and Tiemann, *MTBE in Gasoline: Clean Air and Drinking Water Issues, Update*, 2001.

recommended that the 2.0 percent requirement be "removed in order to provide flexibility to blend adequate fuel supplies in a cost-effective manner while quickly reducing usage of MTBE and maintaining air quality benefits."

However, according to the Congressional Research Service, waiver legislation faces significant opposition:[28]

> *While support for waiving the oxygenate requirement is now widespread among environmental groups, the petroleum industry, and states, a potential obstacle to enacting legislation lies among agricultural interests. About 6 percent of the nation's corn crop is used to produce the competing oxygenate, ethanol. If MTBE use is reduced or phased out, but the oxygenate requirement remains in effect, ethanol use would likely soar, increasing demand for corn. Conversely, if the oxygenate requirement is waived by EPA or by legislation, not only would MTBE use decline, but so, likely, would demand for ethanol. As a result, Members, Senators, and Governors from corn-growing states have taken a keen interest in MTBE legislation. Unless their interests are addressed, they might pose a potent obstacle to its passage.*

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[28] McCarthy and Tiemann, *MTBE in Gasoline: Clean Air and Drinking Water Issues*, 1998.

3. GASOLINE FORMULATION ALTERNATIVES

The current debate on banning MTBE in gasoline has focused on two alternative gasoline formulations: (1) RFG in which MTBE is replaced with ethanol; and (2) a non-oxygenated RFG produced by replacing MTBE with alkylates. Both of these alternatives require that other properties of the gasoline be adjusted to compensate for the changes in fuel characteristics created by the blending of ethanol or alkylates into the fuel.

3.1 Properties of RFG with MTBE

MTBE has several desirable properties as a gasoline oxygenate. To achieve a 2.0 percent by weight oxygen content, MTBE is blended in gasoline at approximately 11.5 percent by volume. Therefore, in addition to adding oxygen to gasoline, MTBE has the effect of diluting other undesirable constituents in gasoline such as benzene and sulfur.[29] MTBE also increases the octane of gasoline and does not adversely affect other important gasoline properties such as RVP and cold weather starting performance. Moreover, RFG made with MTBE is relatively inexpensive and easy to blend, store, and transport.

MTBE has another important attribute: it is derived from natural gas by combining methane (the primary constituent of natural gas) and butane (a natural gas liquid). Most MTBE used in the United States is produced in refineries and merchant plants from natural gas produced in the United States and Canada. Its use in gasoline reduces oil imports by an equivalent quantity (in energy terms) since oil imports are the marginal source of petroleum supplies into the United States.[30] On the other hand, use of MTBE increases U.S. imports of natural gas from Canada. In addition,

about 29 percent of U.S. demand for MTBE is met through imports.[31] Of course, the use of MTBE may adversely impact groundwater. In addition, use of MTBE may increase emissions of formaldehyde.

3.2 Properties of RFG with Ethanol

Ethanol has many beneficial properties when used as a fuel oxygenate. Like MTBE, ethanol increases the octane of gasoline. Moreover, ethanol is produced from corn and other plant materials and is thus a "renewable" fuel. However, ethanol has several undesirable properties as a gasoline additive. Ethanol results in higher VOC emissions from gasoline, and the higher volatility of ethanol makes it harder to meet summertime evaporative emissions criteria (RVP caps) for RFG. To compensate for the higher volatility of ethanol while maintaining performance characteristics such as cold weather starting, the "base" gasoline blend stock must be adjusted. This adjustment is costly and increases the production cost of the resulting RFG. Moreover, since ethanol contains considerably more oxygen (by weight) than does MTBE, RFG with ethanol contains only approximately 5.7 percent ethanol by volume (compared to 11.5 percent by volume for RFG with MTBE). The difference in volume must be made up with gasoline, which leads to a decreased dilution effect from ethanol and ultimately to an increased demand for crude oil.

Ethanol also has lower energy density than MTBE, so RFG made with ethanol results in poorer fuel economy than does RFG made with MTBE. Lower fuel economy performance results in higher costs to gasoline consumers and higher emissions per mile driven (even when emissions per gallon burned are

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[29] According to the U.S. Department of Energy's Energy Information Administration, "MTBE is an important blending component for RFG because it adds oxygen, extends the volume of the gasoline and boosts octane, all at the same time. In order to meet the 2 percent (by weight) oxygen requirement for federal RFG, MTBE is blended into RFG at approximately 11 percent by volume, thus extending the volume of the gasoline. When MTBE is added to a gasoline blend stock, it has an important dilution effect, replacing undesirable compounds such as benzene, aromatics and sulfur." U.S. Department of Energy, Energy Information Administration, "Issues in Focus: Phasing Out MTBE in Gasoline," *Annual Energy Outlook 2000*, 2001a.

[30] Mazur, statement before the Committee on Commerce, Subcommittee on Health and the Environment, U.S. House of Representatives, 2000.

[31] Average for the period 1998–2000. See U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Annual, Volume 1*, 1998, 1999, and 2000.

held constant). Finally, evaporative emissions can increase substantially when a motorist mixes an ethanol blend and ethanol-free gasoline in the same vehicle.

Ethanol is also considerably more difficult to transport and handle in the refining system because it absorbs water and can cause corrosion and other problems in the refinery. Separate storage tanks and handling equipment are required, and ethanol must be transported in dedicated facilities. As a result, ethanol is generally blended into gasoline at distribution terminals rather than at refineries.

Finally, the market price of ethanol is kept artificially low by a federal tax subsidy on ethanol production. The full social cost of ethanol, including the taxpayer cost of the subsidy, is significantly higher than the cost of MTBE.

The use of ethanol may also generate several incremental environmental impacts. These could include increased smog formation from ethanol-containing gasoline, as well as higher levels of acetaldehyde emissions. In addition, ethanol may have adverse impacts on groundwater quality, but, based on available data, they would not be as dramatic as those caused by MTBE.

3.3 Properties of Non-Oxygenated RFG

In order to assess the value of a waiver of the federal oxygenate requirement, this study examined a case in which MTBE is not replaced by an oxygenate such as ethanol. It is possible to produce a fuel that satisfies the CARB predictive model without use of oxygenates by replacing MTBE with alkylates.[32] Other blending adjustments are also required to achieve properties that produce acceptable emissions under the predictive model. In a typical case, switching from MTBE to a purely non-oxygenated fuel requires increasing the volume of alkylates from 14 percent to 25 percent of the gasoline produced.[33]

Alkylates are a high-quality petroleum blend stock and have few undesirable properties other than cost and limited availability.[34] Alkylates are produced in refineries from petroleum feedstocks and, ultimately, crude oil. Gasoline refiners can either purchase alkylates or (at a cost) convert capacity currently used to produce MTBE from petroleum feedstocks to produce alkylates (from isobutylene). In either case, the cost (per gallon) of alkylates to refiners is higher than the cost of MTBE, and a greater volume of alkylates is required per gallon of RFG. Finally, because alkylates are derived from crude oil, replacement of MTBE with alkylates would increase U.S. crude oil imports.

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[32] Schremp, "California's Issues—Expanded Use of Ethanol and Alkylates," 2001; MathPro, *Staff Report: Supply and Cost of Alternatives to MTBE in Gasoline*, 1999c; MathPro, *Staff Report: Supply and Cost of Alternatives to MTBE in Gasoline, Technical Appendices, Refinery Modeling Task 3: Supply Scenario Modeling Runs, Final Report*, 1998.

[33] MathPro, *Staff Report: Supply and Cost of Alternatives to MTBE in Gasoline, Technical Appendices, Refinery Modeling Task 3: Supply Scenario Modeling Runs, Final Report*, 1998. A study by Oak Ridge National Laboratory, *Estimating Refining Impacts of Revised Oxygenate Requirements for Gasoline* (1999), concluded that meeting federal RFG requirements in Petroleum Administration Defense District I (PADD I) in a no-oxygenates case would require alkylates to increase from 10 percent to 35 percent of the gasoline produced.

[34] According to the CEC study, "Alkylate is an important component of EPA-reformulated gasoline produced on the U.S. Gulf Coast (USGC) and is a component of high-value premium gasolines as well as aviation gasolines produced in all regions of the world." (p. 6) "Alkylate is the ideal CARB gasoline blend stock. Alkylate contains no olefins, no sulfur, no aromatics, no benzene and has low vapor pressure. Alkylate has attractive octane characteristics. There is no property relevant to CARB gasoline in which alkylate has poor characteristics. Alkylate from California refiners and that produced elsewhere is essentially the same in all respects." (Pervin & Gertz, "External CARB Gasoline Supply," 1998, p. 68)

4. COST-BENEFIT ANALYSIS

The cost-benefit model and results of this study are first briefly summarized and then the model and data are described in more detail, including discussion of the specific fuel formulations evaluated and the formal treatment of uncertainty in the model. Some of the more complex model calculations are relegated to appendices.

4.1 Components of the Cost-Benefit Analysis

The costs and benefits of switching away from use of MTBE as a gasoline additive can be grouped into three broad areas of impact: (1) the costs of gasoline production; (2) air quality; and (3) water quality.

When replacing MTBE in RFG, a number of factors impact gasoline production costs. These costs can be separated into six components: (1) the change in cost to refiners to manufacture RFG without MTBE; (2) the real resource cost of ethanol production to replace MTBE, including costs that are paid by taxpayers through the ethanol tax subsidy and therefore do not appear in refiners' costs; (3) the cost of the additional fuel that consumers must purchase to meet their driving needs when the miles per gallon obtainable from gasoline changes; (4) the costs to the U.S. economy associated with changes in oil imports; (5) the consumer-surplus loss attributable to reduced fuel consumption; and (6) net changes in producer and consumer surplus and import costs in natural gas markets due to the effects of an MTBE ban on demand for natural gas. All these elements must be estimated simultaneously because all the magnitudes involved depend on how U.S. and global energy markets react to changes in the cost and composition of California gasoline. This analysis includes all costs and benefits that accrue within the United States in order to avoid ignoring either costs or benefits in other parts of the United States attributable to a decision regarding the ban of MTBE in California. Viewing costs and benefits from the perspective of the United States also implies

that changes in the price of imports or exports to produce a net cost or benefit to the United States be considered, even though those changes are transfers from one nation to another.[35]

4.2 Fuel Alternatives Considered in the Cost-Benefit Model

As discussed previously, feasible gasoline alternatives for California are governed by federal and state regulations. Unless the federal oxygenate requirement is waived or repealed, the only feasible legal gasoline formulations for California are RFG with either MTBE or ethanol. Should the federal oxygenate requirements no longer apply but the CARB Phase 3 regulations remain in force, non-oxygenated RFG would also be a feasible alternative.

Only one comprehensive comparison of the refining process and fuel production costs for the three alternative fuels in California has been completed to date. That analysis was commissioned by CEC and is described in a report by MathPro.[36] This study used the estimates provided in that report to compare the properties, emission performance, and cost of the two alternatives that could be adopted under an MTBE ban. This involved first determining what the properties of a reference fuel containing MTBE would have to be in order to meet the future Phase 3 rules and then determining what that fuel would cost to produce. The same steps were followed to determine the properties and cost of the two alternatives.

The composition of the three fuels that satisfy the CaRFG3 regulations is described in Table 3. The reference fuel contains MTBE and is the formulation against which the predictive model compares alternatives to determine the relative merits of their emissions compared to the reference fuel. The two alternatives are an oxygenated fuel that replaces MTBE with ethanol and a non-oxygenated fuel produced by blending additional amounts of alkylates. The ethanol

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[35] This approach is consistent with the available literature on the "oil import premium" and other studies of the costs and benefits of trade policy for the U.S.

[36] Oak Ridge National Laboratory, *Estimating Refining Impacts of Revised Oxygenate Requirements for Gasoline*, 1999.

and non-oxygenated fuel specifications were taken from the MathPro report to CEC.[37] These alternatives require both the purchase of different amounts of blending components and implementation of changes in refinery operations. The relative cost of producing the different fuels was estimated in the MathPro report using a complex refinery linear programming model and was based on those two factors. Table 4 describes the properties of each fuel that are used as inputs to the predictive model to estimate emissions from each fuel.

Table 3. Gasoline Composition and Energy Content -

Composition (percent)	Reference	Ethanol	Non-Oxygenated
C4s	0.5	0.5	0.5
C5s and Isomerate	4.5	6.7	12.6
Naptha	1.5	2.6	0.0
Alkylate	14.7	23.1	26.4
Hydrocrackate	17.4	12.7	9.3
FCC Gasoline	28.5	24.2	22.8
Reformate	21.8	23.9	27.7
Oxygenate	11.5	5.7	0.0
MTBE	10.8	–	–
Ethanol	–	5.7	–
TAME	0.2	–	–
Energy Density (MMBTU per barrel)	5.2	5.1	5.2
Fuel Economy	–	−0.4%	0.8%

Note: C4s and C5s are light hydrocarbon molecules contained in crude oil that are sometimes blended with gasoline.

The emission reductions estimated by the predictive model for each fuel alternative are described in Table 5. The alternative formulations are superior to the reference fuel in each of the three criteria: NOx, total hydrocarbons (THC), and PWT. The fuel alternatives differ in the types of air toxics produced.

For expositional purposes, RFG with MTBE was used as the reference fuel in the cost-benefit model. Costs and benefits of substituting ethanol for MTBE or producing a non-oxygenated fuel were measured relative to continued production of RFG containing MTBE.

Table 4. Fuel Properties Used to Determine Emissions in Predictive Model

Property	Unit	Reference	Ethanol	Non-Oxygenated
Reid Vapor Pressure	pounds per square inch, maximum	6.90	6.60	6.80
T50	degrees F	213.00	2.80	197.00
T90	degrees F	305.00	305.00	304.00
AROM	volume percent, maximum	25.00	24.60	25.80
OLEF	volume percent, maximum	6.00	4.40	5.10
Total Oxygen	weight percent	2.20	2.00	0.00
Oxygen as MTBE	weight percent	2.20	0.00	0.00
Oxygen as ETOH	weight percent	0.00	2.00	0.00
Sulfur	parts per million weight	20.00	20.30	17.00
Benzene	volume percent, maximum	0.80	0.53	0.73

[37] MathPro, *Analysis of California Phase 3 Standards*, 1999a. The ethanol case used is Phase 3 PM, Ethanol 2 percent weight, Reference Fuel A, Case 1a, CARB. The non-oxygenate case is Phase 3 PM, No Oxygenate, Reference Fuel A, Case 1d, CARB.

This analysis concentrated on scenarios where all gasoline in California is of the same formulation (RFG with MTBE, RFG with ethanol, or non-oxygenated RFG). That is, it modeled a switch from 100 percent of the gasoline in California containing MTBE to 100 percent of the gasoline in California containing either ethanol or alkylates. However, not all gasoline in California currently contains MTBE. Moreover, under an MTBE ban, all gasoline probably would not contain ethanol (if a waiver from the federal RFG oxygenate requirement is obtained) or 100 percent alkylates (if a waiver from the federal RFG oxygenate requirement is not obtained). With an MTBE ban but no oxygenate waiver, 70 percent of the gasoline in California would have to contain ethanol but the remainder could contain alkylates. With an MTBE ban and an oxygenate waiver, while no gasoline in California would have to contain ethanol, it is expected that some use of ethanol would occur. Thus, with or without an oxygenate waiver, a "split pool" (whereby both ethanol and alkylates are used in California gasoline) scenario is possible.

Nonetheless, the model accurately reflects the actual costs that will be incurred from a ban of MTBE. For instance, while not all gasoline in California currently contains MTBE, the vast majority does.[38] Therefore, the assumption that all gasoline currently contains MTBE is largely accurate. Moreover, should MTBE be banned but no oxygenate waiver be granted, it is likely that almost all gasoline sold in California would contain ethanol. The use of ethanol would be required in the 70 percent of California gasoline subject to the federal RFG regulations. Moreover, the remaining 30 percent is subject to CARB regulations, and because of logistical considerations, many refiners will be forced to use ethanol to meet the CARB regulations on this gasoline.

Finally, should a split pool result from an MTBE ban (with some gasoline containing ethanol and some gasoline containing alkylates), the costs to California would not be materially different than those predicted for either the 100 percent ethanol (Table 6) or 100 percent alkylates (Table 7) scenarios. This is because the costs of switching from MTBE to either ethanol or alkylates are approximately equal. In addition, most of these costs are proportional to the number of gallons that contain either ethanol or alkylates. Therefore, the cost of switching to a "split pool" is approximately equal to the weighted average cost of the 100 percent ethanol scenario and the 100 percent alkylates scenario (with the weights equal to the percentage of the pool devoted to each alternative). The sensitivity of the model to the possibility of a split pool outcome was tested by modeling a scenario with a 70 percent ethanol/30 percent alkylates split. The results of that analysis were not materially different from either of the 100 percent scenarios (see Table 8).

Table 5. Emission Reductions Relative to Reference Gasoline (Percent)

Pollutant	Ethanol	Non-Oxygenated
NOx	−0.66	−2.54
Exhaust Total Hydrocarbons (THC)	−1.52	−2.10
EVAP THC (Reactivity Weighted)	−6.75	−2.35
CO (Reactivity Weighted)	0.00	0.00
Total THC+CO	−3.00	−2.03
PWT (Potency-Weighted Toxics)	−9.93	−4.18

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[38] See, for instance, Sierra Research, *Potential Evaporative Emission Impacts Associated with the Introduction of Ethanol-Gasoline Blends in California*, 2000: "As the CARB regulations encourage and the U.S. EPA regulations mandate the addition of oxygenates to reformulated gasoline, one direct result has been the addition of the oxygenate methyl tertiary-butyl ether (MTBE) to virtually all gasoline sold in California since 1995." (p. 1) See also CEC, *Staff Report: Supply and Cost of Alternatives to MTBE in Gasoline*, 1999a. Page 12 claims that federal regulations force use of oxygenates over 1.8 weight percent for roughly two-thirds of the fuel sold in the state. As for the remaining fuel sold in the state, it claims, "Even though CARB regulations allow refiners the flexibility to produce gasoline blends containing oxygen at levels below 1.8 weight percent, only a few of them are currently able to reduce their oxygenate use (in the San Francisco Bay Area and limited areas in northern California)." See also CARB, "Notice of Public Hearing to Consider Amendments to the California Reformulated Gasoline Regulations Regarding Winter Oxygen Requirements in the Lake Tahoe Air Basin and Labeling Pumps Dispensing Gasoline Containing MTBE," 1999a: "Although there are several oxygenates that can be used to meet the federal and state oxygen requirements in gasoline, MTBE is used most frequently—in 1996, more than 95 percent of California gasoline was blended with MTBE."

Table 6. Monte Carlo Results (50,000 Repetitions) for Cost of Ethanol Scenario Relative to Cost of MTBE Scenario

Fuel Impacts	Lower Bound	Expected Value	Upper Bound
Effects of MTBE Ban on Natural Gas Demand	($326,086,899)	($178,973,966)	($109,436,920)
Ethanol Tax Credit	444,606,075	445,040,325	445,446,508
Change in Refining Cost, Oil Import Bill, and Consumer Surplus	714,285,315	741,600,202	771,844,699
Total Difference in Fuel Costs	**$832,804,491**	**$1,007,666,561**	**$1,107,854,287**
Air Quality			
Air Toxics	($23,462,241)	($23,462,241)	($23,462,241)
Reduced Fuel Consumption	(6,703,137)	(5,019,566)	(3,319,882)
Total Difference in Air Quality Costs	**($30,165,378)**	**($28,481,807)**	**($26,782,123)**
Water Quality			
Surface Water	($3,720,501)	($2,185,032)	($1,004,466)
Groundwater			
Leaking Underground Storage Tanks (LUSTs)	(522,674,604)	(95,147,308)	(2,986)
Pipelines	(1,511,205)	(447,619)	(12)
Wells	(97,077,585)	(24,940,192)	(1,790,945)
Total Difference in Water Quality Costs	**($624,983,895)**	**($122,720,151)**	**($2,798,409)**
Total Incremental Cost	**$177,655,218**	**$856,464,603**	**$1,078,273,755**

Table 7. Monte Carlo Results (50,000 repetitions) for Cost of Alkylate Scenario Relative to Cost of MTBE Scenario

Fuel Impacts	Lower Bound	Expected Value	Upper Bound
Effects of MTBE Ban on Natural Gas Demand	($326,086,315)	($180,416,789)	($109,436,964)
Ethanol Tax Credit	0	0	0
Change in Refining Cost, Oil Import Bill, and Consumer Surplus	1,200,105,072	1,247,544,796	1,299,168,913
Total Difference in Fuel Costs	**$974,018,757**	**$1,067,128,007**	**$1,189,731,949**
Air Quality			
Air Toxics	($17,124,593)	($17,124,593)	($17,124,593)
Reduced Fuel Consumption	(11,131,338)	(8,295,463)	(5,512,125)
Total Difference in Air Quality Costs	**($28,255,931)**	**($25,420,056)**	**($22,636,718)**
Water Quality			
Surface Water	($3,728,907)	($2,187,922)	($1,017,739)
Groundwater			
Leaking Underground Storage Tanks (LUSTs)	(585,036,509)	(131,147,171)	(4,539,725)
Pipelines	(1,825,614)	(685,458)	(142,261)
Wells	(111,634,002)	(30,731,552)	(3,911,505)
Total Difference in Water Quality Costs	**($702,225,032)**	**($164,752,103)**	**($9,611,230)**
Total Incremental Cost	**$143,537,794**	**$876,955,848**	**$1,157,484,001**

Table 8. Monte Carlo Results (50,000 repetitions) for Cost of Blended (70 percent/30 percent) Ethanol/ Alkylate Scenario Relative to Cost of MTBE Scenario

Fuel Impacts	Lower Bound	Expected Value	Upper Bound
Effects of MTBE Ban on Natural Gas Demand	($326,085,773)	($180,276,728)	($109,436,938)
Ethanol Tax Credit	310,738,396	311,165,832	311,565,800
Change in Refining Cost, Oil Import Bill, and Consumer Surplus	859,863,396	893,554,352	929,834,132
Total Difference in Fuel Costs	**$844,516,019**	**$1,024,443,456**	**$1,241,290,496**
Air Quality			
Air Toxics	($21,560,947)	($21,560,947)	($21,560,947)
Reduced Fuel Consumption	(8,026,297)	(5,988,951)	(3,990,189)
Total Difference in Air Quality Costs	**($29,587,244)**	**($27,549,898)**	**($25,551,136)**
Water Quality			
Surface Water	($3,745,037)	($2,189,025)	($1,010,772)
Groundwater			
Leaking Underground Storage Tanks (LUSTs)	(545,927,022)	(106,310,357)	($3,433,375)
Pipelines	(1,563,083)	(519,092)	(58,185)
Wells	(100,285,424)	(26,740,103)	(2,305,897)
Total Difference in Water Quality Costs	**($651,520,566)**	**($135,758,577)**	**($2,196,435)**
Total Incremental Cost	**$163,408,209**	**$861,134,981**	**$1,213,542,925**

4.3 Treatment of Uncertainty in the Cost-Benefit Model

Factors that affect costs and benefits are usually subject to some degree of uncertainty. Often the degree of uncertainty can be significant, and this uncertainty can affect factors that play an important role in determining the costs and benefits of a decision. In order to reflect this uncertainty in the evaluation of a decision properly, the cost-benefit analysis can include ranges for input values that are subject to significant uncertainty. Many of the factors affecting the costs and benefits of using MTBE or ethanol as a fuel oxygenate are subject to uncertainty. This is particularly true when estimating the impacts of fuel additives on water quality.[39] To gauge the effect of this uncertainty, the costs and benefits can be computed with all uncertain inputs set to the upper end of the range and again when all inputs are set to the lower end of the range.

Thus, the estimated costs and benefits of a particular alternative are presented as a range.

Calculation of costs and benefits with all uncertain inputs set at one end of their ranges is helpful in understanding and presenting the effects of this uncertainty on the outcome of a decision. However, this methodology results in a broad range of total costs or benefits for a particular decision since the total cost-benefit number is calculated on the assumption that *all* uncertain parameters will *simultaneously* be at the same end of the range. While this outcome is theoretically possible, it is unlikely. Therefore, the analysis also included a more formal and rigorous "Monte Carlo" treatment of the uncertainty surrounding certain input parameters.

Monte Carlo analysis is a mathematical simulation analysis where a probability distribution is specified for each of the uncertain parameters rather than just their respective upper and lower bounds. For

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[39] For instance, as discussed later, there is significant uncertainty about the degree to which LUST (leaking underground storage tank) plumes that contain MTBE are longer than LUST plumes from conventional gasoline. This leads to uncertainty about the degree to which LUST plumes that contain MTBE would be more costly to clean up than plumes from conventional gasoline.

each iteration or "run" of the Monte Carlo analysis, a single value for each uncertain parameter is randomly selected from the specified probability distribution, and the cost-benefit calculation is performed using these parameter values. The distribution of the parameters that were varied in the Monte Carlo analysis in this study is described in Table 9. All the elasticities that determine fuel market responses move together.[40] If no relationship is specified, other distributions are independent. The Monte Carlo analysis is repeated for a large number of runs (in this case, 50,000), resulting in a distribution of outcomes (final cost-benefit totals). This distribution can then be used to estimate the average (or expected) costs or benefits, as well as the range of outcomes likely to occur with, for example, greater than 5 percent probability.

4.4 Changes in Gasoline Production Costs

There are a number of factors that influence the cost of producing RFG (see Figure 1 for an overview). The additives themselves—MTBE, ethanol, and alkylates—differ in cost to the refiner. Although some MTBE and alkylates can be produced at a refinery, a market exists for each alternative additive with relative pricing varying over time with the supply and demand of the different additives. All three additives have high octane ratings, so their use makes it

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[40] In other words, the Monte Carlo analysis in this study used a single randomly selected value. This control parameter selects, for each elasticity, a convex combination of the high and low values that define that elasticity's range. Because the same choice of control parameter is used across different elasticities for a given run, the elasticities move together.

Table 9. Distribution of Parameter Values Used in Monte Carlo Analysis

	Distribution of Parameter
Fuel Impacts	
Refined Products Elasticity	Uniform (−0.08, −0.16)
Gasoline Elasticity	Uniform (−0.2, −0.4)
Natural Gas Supply Elasticity	Uniform (0.25, 0.75)
Natural Gas Demand Elasticity	Uniform (−0.09, −0.27)
Vehicle Miles Traveled Elasticity	Uniform (0.1, 0.2)
Water Impacts	
General	
Plume Ratio	Clipped Chi-Square (0.0745, 1) -
Number of Years of Treatment	Equal Probability on {2, 3, 4, 5} -
Surface Water	
Monitoring Cost	Clipped Normal (10,000, 25,000) -
Number of Reservoirs	Uniform (100, 150) -
Pipelines	
Leaks per Year	Clipped Normal (5, 10) -
Cost without MTBE	Uniform (105,000, 186,666) -
Increased Cost due to MTBE	Uniform (0.25, 1.00) -
Wells	
Probability of Well Impact with MTBE	Fixed (0.75) -
Number of Private Wells	Uniform (1,236, 5,440) -
Cost of Private Treatment	Uniform (1,000, 2,000) -
Number of Public Wells	Uniform (6.66, 46.66) -
Cost of Public Treatment	Uniform (30,000, 105,882) -
Underground Storage Tanks	
Leakage Rate Upgraded	Uniform (0.0007, 0.02) -
Leakage Rate Not Upgraded	Uniform (0.025, 0.03) -
Existing Impacting Sites	
Cost of Natural Attenuation	Uniform (25,000, 50,000) -
Cost of Active Remediation	Uniform (55,000, 180,000) -
Special Joint Distributions	
Investigation Cost	
Without MTBE	Uniform (20,000, 170,000)
With MTBE	Uniform (Previous draw, 250,000)
Percent Natural Attenuation	
Without MTBE	Fixed: 90 percent -
With MTBE	Fixed: 10 percent -

possible to cut down on the use of other costly octane enhancers. Ethanol, even when added in small quantities, has the unique problem of greatly increasing the volatility of gasoline. In order to meet restrictions on gasoline volatility, ethanol blends must eliminate other volatile compounds in the gasoline blend. Replacing these volatile compounds with other additives, while maintaining easy engine starting and octane, is costly. As an alternative, refiners can make capital investments so that the properties of gasoline feedstocks can be altered within the refinery, and frequently this is less costly than purchasing needed additives.

Ethanol needs to be handled differently from other additives in order to prevent corrosion and other operational problems. Typically, ethanol is blended into a gasoline base (called CARBOB or CARB Oxygenate Blendstock) after it leaves the refinery. This requires additional blending facilities and separate storage and handling facilities for ethanol, CARBOB, and finished oxygenated gasoline. Alkylates and ethanol are mostly produced outside of California, so their delivered prices include large transportation costs, estimated by the Department of Energy to be about $0.15 per gallon.[41]

Ethanol also contains less energy per physical gallon than MTBE does, so when ethanol is utilized the fuel economy experienced by motorists declines. This is a true increase in cost to consumers, and this study estimated the increase in the effective price of gasoline due to the loss in fuel economy. Alkylates, on the other hand, contain more energy per physical gallon than MTBE, which reduces the effective price of gasoline. An additional cost factor comes from blending formula patents that recently have been claimed by Unocal. These require refiners to either pay royalties, to which two refiners are reported to have agreed, or incur additional costs to use more expensive blending techniques to avoid violating the patents.

4.4.1 Refinery Costs

A number of studies have estimated the cost of producing RFG containing MTBE. Some of these studies were done prospectively and relied on a variety of assumptions about the form of final federal and California rules. The National Petroleum Council (NPC) prepared a study in 1993 that estimated a range of costs to the refiner for producing RFG using MTBE to specifications similar to the California Phase 2 program. NPC estimated that RFG would cost from 3 to 7 cents per gallon more than conventional gasoline of the type produced before 1990.[42] In addition, NPC estimated that there would be additional logistics and marketing costs of about 2.5 cents per gallon associated with RFG production. The NPC estimates and other contemporary studies were designed to address questions about the costs and benefits of replacing conventional gasoline, as it was formulated before 1990, with a cleaner-burning RFG. Their estimates are largely irrelevant to the question of the costs and benefits of replacing MTBE in RFG with ethanol or alkylates. Thus, this cost-benefit analysis began by estimating the difference between the costs of an MTBE-based product and the alternatives to this product.

In a study done for the CEC, the cost of producing RFG using ethanol was estimated by MathPro to be 4.4 cents per gallon more than the MTBE-based reference fuel.[43] This cost included all refining costs (3.2 cents per gallon), ancillary and logistics costs (0.4 cents per gallon), and the value to the consumer of lost fuel economy (0.8 cents per gallon). This differential is largely consistent with findings of the U.S. Energy Information Administration and Oak Ridge National Laboratory.[44] These costs are only incurred during the summer RFG season. During winter, the less strict RVP requirements make producing RFG approximately

[41] U.S. Department of Energy, Energy Information Administration, "Issues in Focus: Phasing Out MTBE in Gasoline," *Annual Energy Outlook 2000*, 2001a, p. 33.

[42] Zyren et al., "1995 Reformulated Gasoline Market Affected Refiners Differently," 1996.

[43] CEC, "Analysis of the Refining Economics of California Phase 3 RFG," Exhibit 6, 1999b, as updated to more conservative estimates based on more current data supplied by the authors.
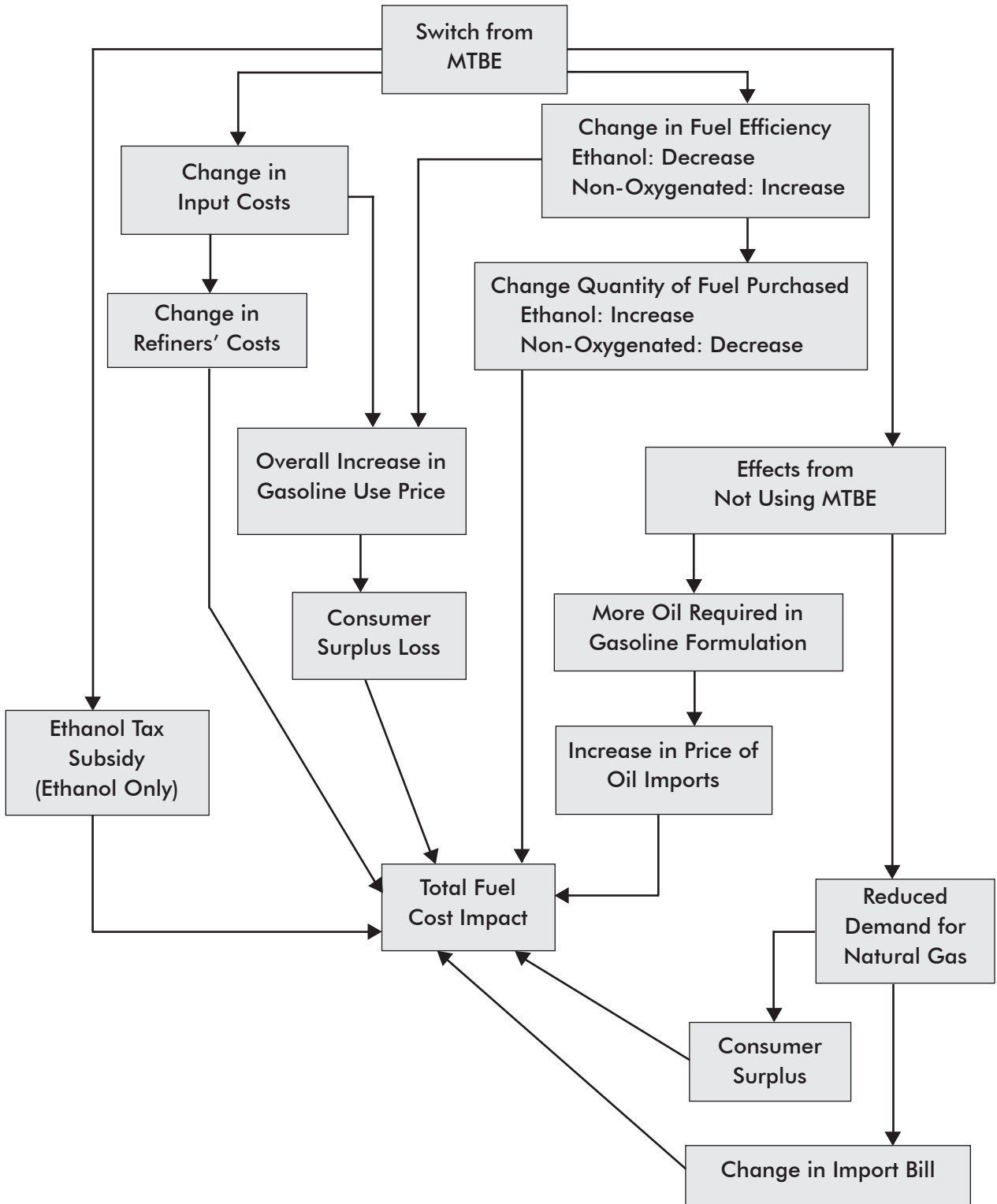
[44] U.S. Department of Energy, Energy Information Administration, "Issues in Focus: Phasing Out MTBE in Gasoline." *Annual Energy Outlook 2000*, 2001a; Oak Ridge National Laboratory, *Estimating Refining Impacts of Revised Oxygenate Requirements for Gasoline*, 1999.

Figure 1. Overview of Fuel Cost Impact of Switching from MTBE -

the same as conventional gasoline, so that the total cost associated with RFG is just the ancillary plus fuel economy cost, or 1.2 cents per gallon in winter. The ethanol price used in this CEC study was the effective cost to the refiner, which is less than the cost of producing ethanol by the amount of the blender's tax credit.

To estimate year-round costs, in this study these seasonal costs were blended summer 68 percent/winter 32 percent to reflect different fuel requirements. The result is a final refiner cost equal to 2.36 cents per gallon year round and a final user cost equal to 3.16 cents per gallon.

To estimate the annual increase in production costs to California, the increase in cost per gallon was multiplied by total consumption of gasoline in California, which was approximately 14.5 billion gallons in 2000.[45] In order to take into account the effect that the higher gasoline prices caused by an MTBE ban would have on demand for gasoline, the estimate of gasoline consumption used in this calculation had to be reduced below the actual amount that is consumed in the absence of an MTBE ban.[46] The expected annual increase in refinery costs attributable to using ethanol in RFG, relative to continued use of MTBE, is approximately $341 million per year.

The same CEC report that estimated the additional cost to produce RFG from ethanol in California also evaluated a formulation for a non-oxygenated gasoline that would satisfy the proposed CARB Phase 3 regulations. The report estimated the costs of producing the non-oxygenated fuel to be 4.9 cents per gallon, including all refining costs (5.5 cents per gallon), ancillary and logistics costs (0.3 cents per gallon), and an offset for the value to the consumer of improved fuel economy (for which this study used a value of 0.9 cents per gallon). Obviously these results are for

the non-oxygenated option and thus differ from the oxygenated-with-ethanol option.[47] The CEC study by MathPro presumed that 100 percent of gasoline sold in California would be non-oxygenated. Oak Ridge National Laboratory performed a similar study for Petroleum Administration for Defense District I (PADD I) (the East Coast) and concluded that a non-oxygenated gasoline would cost 2.4 to 6 cents per gallon more than federal RFG.[48]

In this study, the increase in cost per gallon was multiplied by total consumption of gasoline in California to estimate the annual increase in refining cost (as it was in the ethanol case). Due to the effect that higher gasoline prices would have on demand for gasoline, the estimate of non-oxygenated gasoline consumption used in this calculation was also less than the amount that would be consumed in the absence of an MTBE ban. The expected increase in refinery costs from replacing MTBE with a non-oxygenated gasoline is approximately $835.3 million per year.

4.4.2 Fuel Economy

When the effective fuel economy of gasoline drops, consumers must purchase additional fuel to make up for the reduction in fuel economy. A real cost per gallon of oxygenated fuel due to its reduced fuel economy is therefore the percentage reduction in fuel economy multiplied by the price of gasoline. The decrease in fuel economy is calculated from the difference in energy density of conventional and oxygenated gasoline, as stated in Table 3. The 4.4 cent per gallon differential between the refinery cost of using ethanol instead of MTBE to produce RFG (discussed above) includes a 0.8 cent per gallon penalty for mileage loss, while the 4.9 cent per gallon differential in the cost of non-oxygenated fuel includes a 0.6 cent per gallon

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[45] U.S. Department of Energy, Energy Information Administration, *Petroleum Supply Monthly*, 2001c.

[46] Based upon the available literature, a range of price elasticities of demand for gasoline was used to calculate the reduction in demand that would be caused by the higher price if the ethanol option is used. The basis for the choice of these elasticities and details of the calculation are provided in Appendix A.

[47] In its 1998 CEC report, MathPro estimated a range of 1.9 to 8 cents per gallon, depending on whether the flat or averaging limits of the predictive model are used and how much time is allowed for refiners to make capital investments to change refiner configurations.

[48] Oak Ridge National Laboratory, *Estimating Refining Impacts of Revised Oxygenate Requirements for Gasoline*, 1999.

credit. Therefore, the fuel economy costs and benefits of MTBE alternatives are captured in the subtotals discussed previously.

4.4.3 Gasoline Demand

The previously calculated increase in cost of producing RFG with either ethanol or alkylates only applies to the amount of gasoline actually produced and consumed, which is expected to decline when the higher cost of RFG with ethanol or alkylates decreases consumption from current levels. However, when a price increase reduces demand, there is an additional loss in consumer welfare equal to the value to the consumer of the foregone consumption less the price that was paid for that consumption. This welfare loss is a real economic cost and must be added to the refinery cost increase calculated based on the lower level of consumption. Appendix A derives the mathematical formula used to calculate the loss in consumer surplus and the price, gasoline consumption, and elasticity values used in the calculation.

Figure 2 provides a schematic representation of the two calculations that are involved. The line labeled D_G is the demand curve for gasoline in California. The horizontal line labeled S_G is the supply curve (marginal cost curve) for RFG containing MTBE, and the line labeled S'_G is the supply curve for gasoline with an MTBE ban. The supply curve is shifted up by the estimated increase in cost of producing a gallon of RFG (including an adjustment for the change in fuel economy). This study assumed that the marginal cost of producing RFG is constant and increased at every level of output by the estimated increase in cost. This simplified both the exposition and the calculations and was a reasonable approximation of market behavior when refineries operate at normal capacity levels. Since the likely effect of an MTBE ban is to reduce refining capacity, this assumption

tends to underestimate impacts of an MTBE ban on market prices and therefore underestimates welfare losses to consumers. Under these circumstances, the market price rises by the amount of the cost increase per gallon, and demand is reduced by the amount indicated. The *rectangle A* is the increase in cost of producing RFG estimated in the previous section. The *triangle B* is the loss in consumer welfare due to reduced consumption of gasoline.

4.4.4 Oil Imports

Replacing MTBE with either alkylates or ethanol increases total petroleum use in the United States and, as a result, increases oil imports. Many social costs of oil imports have been cited in the literature,[49] but this study included only a cost that has a clear economic rationale. This is the increase in the price of imported oil that is caused by higher levels of oil imports. This price increase is in a sense an externality of oil consumption because no individual oil consumer (or producer) has an incentive to consider how higher prices affect all other consumers (or producers). In fact, the higher price of oil represents a transfer payment, but the payment is from the United States to

Figure 2. **Consumer Surplus Loss Due to Higher Gasoline Price**

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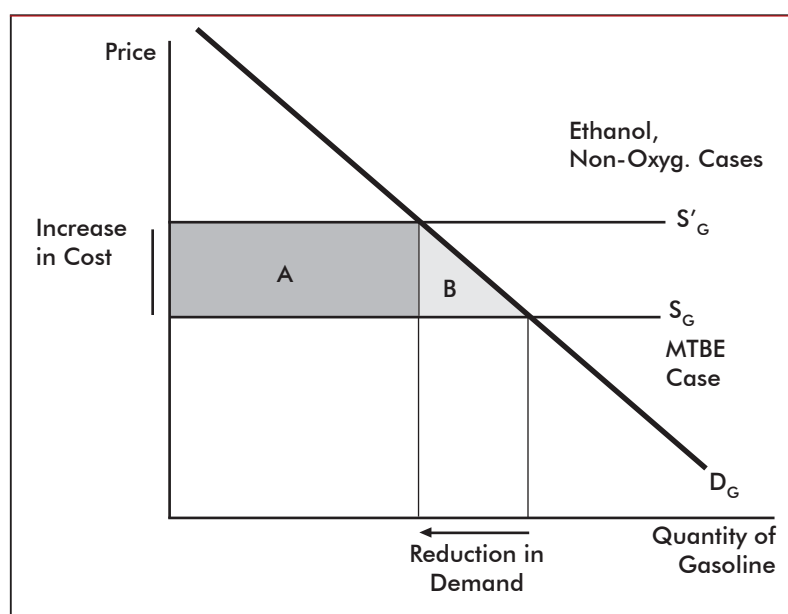
[49] See Green and Leiby, "The Social Costs of the U.S. Monopolization of the World Oil Market, 1927–1991," 1993. See also Bohi and Montgomery, "Social Cost of Imported Oil and U.S. Import Policy," 1982b; and Broadman and Hogan, "Is an Oil Tariff Justified? The Numbers Say Yes," 1988.

foreign oil producers. Therefore, from the point of view of the United States, the additional payments for oil that would have been consumed even at lower prices are a net cost.

The impact on oil imports of replacing MTBE with alkylates in non-oxygenated gasoline is straightforward.[50] Alkylates are petroleum products, so a one-for-one substitution (in energy terms) of oil imports for MTBE was assumed. The impact of replacing MTBE with ethanol is more complex. MTBE is largely produced from domestically produced natural gas, and ethanol is produced from agricultural products, so if equal quantities of ethanol and MTBE were used, there would be no impact on U.S. oil imports. However, MTBE contains less oxygen by weight than ethanol. Therefore, to produce a fuel containing 2.0 percent oxygen requires adding only 5.7 percent ethanol but a full 11.5 percent of the final volume of MTBE. The difference, 5.8 percent of the gasoline sold in California, must be made up with petroleum-based blending components. This increased use of petroleum contributes to greater oil imports.

Two other factors must be taken into account in calculating the effect on oil imports. One is the energy content of the blending components being substituted for gasoline. Lower fuel economy per gallon must be made up with a greater total volume of gasoline purchases. This also increases oil imports. On the other hand, a reduction in total demand for gasoline due to higher gasoline prices tends to reduce oil imports. All these factors are included in the calculation of the net change in oil imports in an ultimate supply and demand equilibrium.

Thus the calculation of the social cost of increased oil imports included the following steps: (1) quantify the amount of petroleum feedstock required to replace natural-gas-based MTBE under ethanol and non-oxygenated fuel cases; (2) estimate the shifts in the demand curve for oil imports attributable to the loss of MTBE, the higher cost of refining, and the change in energy density of delivered fuel; and (3) estimate the new equilibrium world oil price and level of U.S. imports. This study used a simplified model of world

oil supply and demand to estimate the changes in oil prices that would result from the shift in U.S. demand for imports caused by an MTBE ban (see Appendix A). Based on the results of modeling the impacts of the MTBE ban on world oil markets and U.S. imports, two additional steps were required: (4) calculate the transfer of wealth from U.S. to oil exporting countries—the new level of imports multiplied by the world oil price; and (5) calculate the additional loss in consumer and producer surplus due to the impact of higher world oil prices on domestic oil production and end use consumption.

Figure 3 illustrates how the last two steps in the calculation were carried out.[51] A net loss to the U.S. economy is caused by the increase in additional oil required to make up the lost volume of non-petroleum oxygenates and the loss in fuel economy that occurs when ethanol or another substitute replaces MTBE. This increased consumption of oil drives up the world oil price through the operation of supply and demand on world oil markets. Figure 3 shows how the increase in world oil prices reduces U.S. welfare. *Triangle A* is made up of two costs: the incremental cost of increased domestic oil production and the loss in consumer surplus due to the lower oil consumption that results from higher prices. *Rectangle B* is the largest part of the cost. It is the additional amount paid for every barrel of oil imported due to the increase in world oil prices. World oil prices rise because of the increase in world oil demand to replace MTBE with petroleum-based feedstocks.

To estimate the magnitudes of *A* and *B*, total gasoline consumption in California was calculated in millions of barrels per day (MMBD). Then the loss in volume of oxygenates was calculated based on the difference in volume of MTBE (11.5 percent) and ethanol (5.7 percent). MTBE is produced from methanol, a non-petroleum fuel. This difference must be made up with more gasoline feedstocks. This result was offset by the loss in volume associated with the reduction in demand due to higher prices of RFG containing ethanol. This gave the net change in refinery inputs required to produce the volume of gasoline

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[50] A model of the California gasoline market and its connections with the world oil market is provided in Appendix A. Here the discussion generally addresses the calculations, their rationale, and the resulting estimates of social costs of an MTBE ban.

[51] For a more complete discussion of the social costs of oil imports, see Bohi and Montgomery, *Oil Prices, Energy Security, and Import Policy*, 1982a.
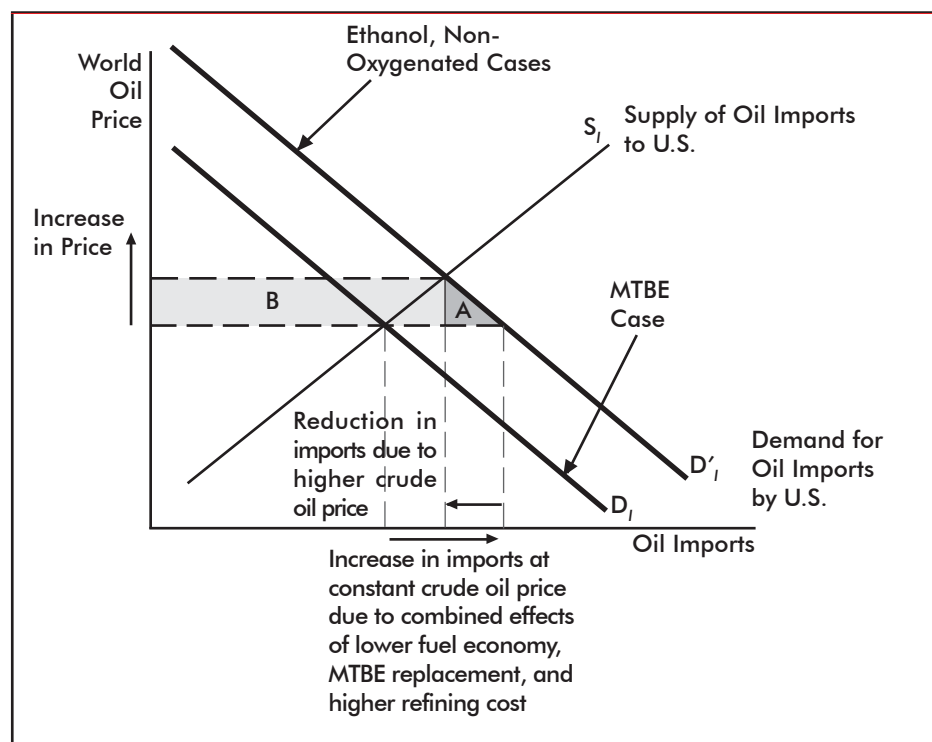
demanded. The increase in refinery inputs equates to an equal increase in crude oil demand (ignoring refinery losses, which actually would require about a 2 percent larger increase in crude oil inputs) at pre-MTBE-ban world oil prices.

This study calculated the required additional supply of crude oil in barrels per day and then calculated the effect of this increase in demand on prices in the world oil market model. A range of demand and supply elasticities was used to determine how much the price must increase to reduce demand and increase supply to balance the world oil market.[52]

Figure 3. Social Cost of Higher Oil Imports

Multiplying the increase in the price of crude oil by the new equilibrium level of U.S. oil imports calculated the increased cost to the United States.

The cost-benefit analysis must also take into account the fact that this price increase will further reduce oil demand in the United States and divert economic resources to production of oil with marginal costs greater than the previous equilibrium crude oil price. The additional domestic supply and lower consumption would reduce the cost of additional oil imports compared to what it would be without a behavioral response, but would add producer and consumer surplus losses. Both these effects were incorporated into the model by adding the consumer and producer surplus loss *A* to the calculated change

in cost of imports *B*, which must be based on the new equilibrium quantity of imports multiplied by the change in price.

As a result of the preceding computations, the increase in the U.S. import bill adds between $255 and $312.3 million annually to the cost of replacing MTBE with ethanol. The increased cost of an MTBE ban in which a non-oxygenated fuel is the replacement is between $444.3 and $541.4 million annually. It turns out that a change of approximately 6 percent in crude oil used for producing gasoline in California is sufficient to cause a small but significant change in world oil prices, which, when multiplied by the volume of U.S. imports, produces an impact in the hundreds of millions of dollars.[53]

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[52] The world oil model uses an elasticity of world crude oil supply of 0.2, based on the elasticity of supply implied by the world oil supply model used by the U.S. Department of Energy's Energy Information Administration in its *International Energy Outlook* (1999). This study used a range of elasticities of demand for gasoline and other refined products in the U.S. and overseas. These elasticities were chosen based on the econometric literature and imply end-use elasticities of demand ranging from approximately 0.3 to 0.8. The elasticity of supply of imports to the U.S. combined both world supply elasticities and demand elasticities outside the U.S. Since refining margins and taxes make the price of products sold to consumers several times larger than the price of crude oil, the elasticity of demand for crude oil is equal to the ratio of the crude oil price to the refined product price multiplied by the price elasticity of demand expressed in terms of refined product prices.

[53] Tables 6, 7, and 8 report an estimate for the total of the refining costs, import costs, and consumer surplus losses described earlier. It is not possible to factor this total neatly into separate estimates for each of these components because all must be estimated simultaneously. The estimate of oil import costs given here is an approximation provided for perspective on the relative magnitude of the different effects.

4.4.5 Ethanol Tax Subsidies

Use of ethanol as a fuel additive is subsidized by the federal government (in the form of an exemption from the gasoline excise tax). Therefore, the cost to refiners for ethanol is substantially less than the cost to produce this ethanol. To calculate the full social cost of an MTBE ban, it is necessary to include the full cost of producing ethanol because that cost represents the value of society's resources used to produce ethanol and not available for other purposes. Ethanol currently receives a federal excise tax exemption of 52 cents per gallon, which is scheduled to decline to 51 cents in 2005. Legal authority for the federal tax exemption expires in 2007, but this exemption has been renewed several times since it was initiated in 1978.

The tax exemption from the federal Motor Fuels Excise Tax goes into the Highway Trust Fund, which largely serves the purpose of funding highway construction and maintenance. Therefore, the excise tax can be seen as a Pigovian tax that internalizes the costs of the roads and highways to the motorists who use them. As a result, any reduction in the tax on gasoline containing ethanol provides ethanol users with an inappropriate incentive to drive more and imposes more costs on the highway system. Such costs were not included in this study's cost-benefit model.

It was claimed in studies done before 1996 that the reduction in federal motor fuel taxes granted to ethanol had either neutral or beneficial revenue impacts on the federal budget because it raised corn demand and market prices and reduced deficiency payments to farmers.[54] Even at the time, that conclusion was dubious because it was based on a particular set of assumptions about how the Secretary of Agriculture would exercise discretion in managing the acreage reduction program. Moreover, the 1996 Farm Bill effectively made payments to farmers independent of market prices. Therefore, recent studies all agree that ethanol subsidies have no direct effect on outlays for farm income support.[55]

It should also be noted that the debate about whether or not ethanol subsidies reduce other farm support payments has nothing to do with accurately measuring the real resource cost of producing ethanol. The real resource cost of producing ethanol is unambiguously the pre-tax cost of production with no adjustment for the tax subsidy. This is the cost of economic resources that is incurred to produce each gallon of ethanol required to replace the corresponding amount of MTBE. This use of resources is incurred whether or not some other form of subsidy to farmers would be adopted to replace the existing ethanol subsidies. The market price of ethanol falls short of the full resource cost by the amount of the tax subsidy, since in competitive markets that subsidy is shifted forward to ethanol purchasers. Therefore, it is under all circumstances correct to add the tax subsidy, which is a pure transfer payment, to the market price of ethanol in order to calculate the marginal cost of producing ethanol for purposes of the cost-benefit analysis.

The CEC report's calculations of the cost differential due to use of ethanol were based on the post-tax-credit cost of ethanol and the assumption that refiners were benefiting from the blenders' tax credit to reduce the cost of purchased ethanol. In 2000, the subsidy for the ethanol contained in a blend of 90 percent gasoline and 10 percent ethanol was 54 cents per gallon. In the scenario in which ethanol substitutes

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[54] U.S. General Accounting Office, *Ethanol Tax Exemption*, 1995; Urbanchuk, *An Analysis of the Full Implications for Federal Government Revenues and Outlays of the Partial Exemption for Alcohol Fuels from Excise Taxes on Motor Fuels*, 1995.

[55] U.S. Department of Agriculture, Office of the Chief Economist, *Economic Analysis of Replacing MTBE with Ethanol in the United States*, 2000: "The increase in ethanol production with a MTBE phase-out would be eligible for the federal excise tax exemption on gasoline, or equivalent tax credit which would reduce federal tax revenues. The exemption is currently $0.54 per gallon and it is scheduled to drop to $0.53 on January 1, 2001, $0.52 on January 1, 2003 and $0.51 on January 1, 2005. Under the current law, the tax exemption expires on December 31, 2006. 'Under the FY 2000 President's Budget baseline, farm crop prices are expected to strengthen from current levels, which results in increased ethanol use having little to no impact on the cost of farm price and income support programs during the projection period . . .' and since 1996 Farm Bill production flexibility contract payments are not tied to the level of market prices, these farm program costs do not fall as market prices of corn and other grains increase, compared with the baseline." Hence this analysis was based on the U.S. corn policy regime reflected in the 1996 Farm Bill. Please note, however, that an expansion of corn demand resulting from an expansion in ethanol demand will not necessarily lead to higher equilibrium corn prices. Such potential outcomes will depend on corn supply response under alternative farm subsidy programs.

for MTBE, the tax subsidy would be applied to all the ethanol used in California. This analysis calculated the quantity of ethanol required for the 5.7 percent blend of ethanol that provides 2.0 percent oxygen content by weight and multiplied that by the subsidy of $0.03078 per gallon, which results in a total increase in costs of $444.6 to $445.4 million per year, relative to the use of MTBE. This cost would be higher for blends containing more ethanol. This analysis assumed that additional capacity was added to produce the incremental ethanol used in California without reducing ethanol use elsewhere in the nation.

4.4.6 Natural Gas Markets

Since an MTBE ban would tend to reduce natural gas demand, it is also important to take into account this possibly beneficial spillover effect of an MTBE ban. Accordingly, it was necessary to calculate the consumer and producer surplus gain in the remainder of the natural gas market when use of natural gas and natural gas liquids as MTBE feedstocks is eliminated. Although in British thermal unit (BTU) terms the reduction in natural gas demand is the same as the increase in petroleum demand in each case, the economic consequences are quite different.

Reduced demand for natural gas as an MTBE feedstock would lead to a lower price in the North American natural gas market. The worst case was assumed to be that all the MTBE used in U.S. refineries is produced from North American natural gas feedstocks. If some MTBE or methanol as a feedstock is imported from other locations, the benefits calculated in North American gas markets would be less. Again, the analysis used a simple mathematical model of the North American gas market that contained supply and demand curves for both the United States and Canada to calculate these impacts (see Appendix A).

The analysis of the effect of an MTBE ban on natural gas is illustrated in Figure 4, which represents supply of and demand for imports of natural gas to the United States. The horizontal distance between the two demand curves is the reduction in demand for natural gas as an MTBE feedstock. This reduction in demand lowers the equilibrium price of natural gas and reduces domestic natural gas production. As a result of the lower price, consumption of natural gas for purposes other than production of MTBE increases. *Triangle A* represents the gain in consumer surplus associated with increased demand at the lower price plus the gain in producer surplus from the reduction in supply, which lowers the cost of producing domestic natural gas.[56] *Rectangle B* represents the gain to the U.S. economy from purchasing natural gas imports at a lower price. Natural gas is largely a domestically produced fuel, and the reduction in price of domestically produced natural gas is a transfer that occurs within the United States and falls out of the calculation of social costs. However, in 2000 the United States imported from Canada about 3.8 trillion cubic feet (TCF) of the nation's total consumption of

Figure 4. Spillover Effects on Natural Gas Markets

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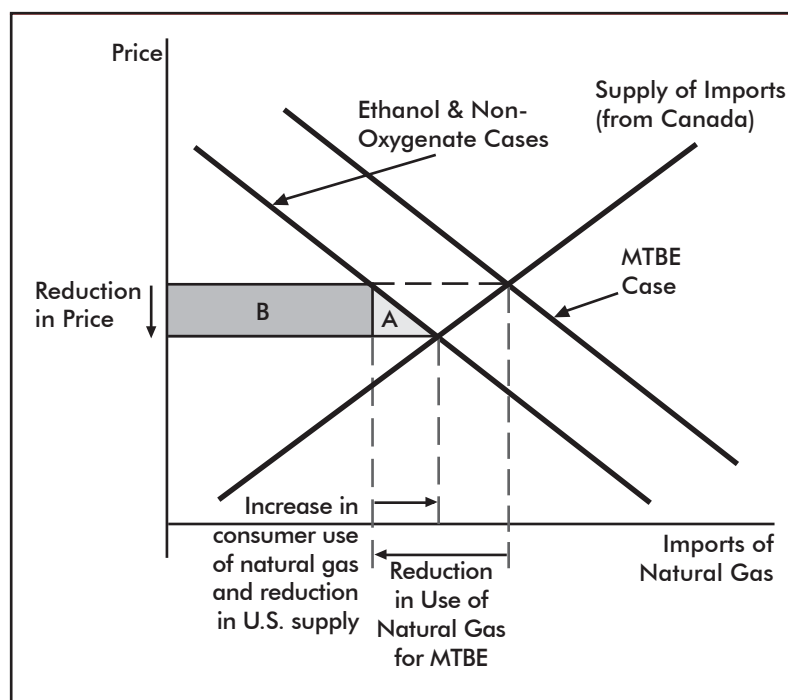
[56] The square below *B*, which represents the remainder of the savings as a result of no longer producing natural gas for an MTBE feedstock, was accounted for in the original calculation of the cost of substitutes minus the cost of MTBE since the cost of natural gas is part of the cost of MTBE.

about 22.5 TCF of natural gas, so some of this transfer is from Canadian producers to U.S. consumers. The reduction in the price of natural gas imports is a net benefit to the U.S. economy. The calculation is exactly the same as the one shown in Figure 3, except that, in proportion to the size of the market, *rectangle B* is not nearly as important.

The social cost of natural gas imports was considerably less important in 1990 than in 2000. In 1990 the Energy Information Administration forecast 1.5 TCF of imports from Canada in 1996 out of a total consumption of 19.17 TCF, so the predicted gains in natural gas trade with Canada would have been much smaller at that time.

Appendix A provides a mathematical derivation of the formulas used to calculate consumer and producer surplus and discusses price, quantity, and elasticity assumptions.[57] The benefit to natural gas markets is due to eliminating the 11.5 percent of gasoline consumption accounted for by MTBE, which will happen under an MTBE ban regardless of whether ethanol or a non-oxygenated fuel provides the replacement. Therefore, the benefit is the same in either case. The expected net gain in producer and consumer surplus, plus the expected savings on the gas import bill due to lower prices being paid for remaining imports, ranges from a minimum of $109.4 million to a maximum of $326.1 million per year with an expected value of $179 million per year.[58]

4.4.7 Other Fuel Cost Issues

There are a number of qualitative issues associated with banning MTBE, some of which point to the possibility of greater gasoline price shocks in the event an MTBE ban is implemented more rapidly than markets can adjust. The first issue relates to existing patents. The Supreme Court recently upheld a decision of lower courts granting Unocal a patent covering most of the cost-effective formulas for blending RFG. Since then, there have been reports that two refiners, Tesoro and CITGO, will pay 1.2 to 3.4 cents per gallon in royalties. Other refiners are planning on "blending around" the patents.[59] Unocal's patents increase the cost to refiners of producing RFG. If this were purely a question of paying the royalty, it would be a transfer from consumers to Unocal and would not affect real resource cost. However, there are strong indications that a number of refiners intend to blend around Unocal's patent and, in so doing, will indeed incur higher real costs. Moreover, a ban of MTBE will make it more difficult to blend around the patents. Without MTBE, it is much more difficult to maintain octane and volatility without using the formulations patented by Unocal.

Issues of capacity and cost will be exacerbated by new federal standards for sulfur in gasoline that become effective in 2006. Meeting these standards will reduce the volume of gasoline that can be produced from existing refineries, effectively reducing their capacity. Use of MTBE simplifies the task of reducing the sulfur content of gasoline. In the absence of MTBE limitations, more MTBE would likely be added to gasoline in the future to help replace octane and volume lost due to desulfurization. If MTBE is no longer an option, extra ethanol may have to be added to maintain octane and volume levels while achieving lower sulfur levels in gasoline.

Still another issue relates to transportation capacity and associated costs for each of the three options.

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[57] To estimate impacts of lower MTBE demand on natural gas markets, a recent study by the National Petroleum Council is particularly useful. See *World Fuels Today*, "Refiner Bottleneck Key to Rising Summer Gasoline Prices," 2001. The council examined a number of alternative scenarios for natural gas supply and demand. By comparing two scenarios with different rates of economic growth, the effects of different levels of demand on prices could be isolated. The council estimated that an additional 0.6 TCF of demand for natural gas in 2010 would increase wellhead prices by about 30 cents per million BTU. This suggests that removing the approximately 0.2 TCF of natural gas and natural gas liquids required to produce MTBE would reduce natural gas prices by about 4 cents per gallon. This would produce a savings of about $144 million on natural gas imports in 2000 and $175 million in 2002.

[58] The modeling used a wide range for natural gas supply and demand elasticities and linked changes in oil markets directly to changes in natural gas markets. Although oil and gas demand were treated as independent, the range of end-use elasticities used was sufficiently large to cover any likely cross-elasticities.

[59] *World Fuels Today*, "Refiner Bottleneck Key to Rising Summer Gasoline Prices," 2001.

According to the U.S. Energy Information Administration (EIA).[60]

> *The prospect of increased use of ethanol also poses some logistical problems. Unlike gasoline blended with MTBE and other ethers, gasoline blended with ethanol cannot be shipped in multi-fuel pipelines in the United States. Moisture in pipelines and storage tanks causes ethanol to separate from gasoline. When gasoline is blended with ethanol, the petroleum-based gasoline components are shipped separately to a terminal and then blended with the ethanol when the product is loaded into trucks. Thus, changes in the current fuel distribution infrastructure would be needed to accommodate growth in "terminal blending" of ethanol with gasoline. Alternatively, changes in pipeline and storage procedures would be needed to allow ethanol-blended gasoline to be transported from refineries to distributors.*
>
> *Ethanol supply is another significant issue, because current ethanol production capacity would not be adequate to replace MTBE nationwide. At present, ethanol supplies come primarily from the Midwest, where most of it is produced from corn feedstocks. Shipments to the West Coast and elsewhere via rail have been estimated to cost an additional 14.6 to 18.7 cents per gallon for transportation. If the demand for ethanol increased as a result of a ban on MTBE, ethanol would need to be produced as a fuel on a regular basis; however, higher prices could make new ethanol facilities economically viable, and sufficient capacity could be in place depending on the timing of the MTBE ban.*

Alkylates will also have to be shipped in large part from the Gulf Coast. Their prices soared on the Gulf Coast in 2001, to 35–40 cents per gallon above historic levels.[61] Alkylates are also likely to be required in increasing amounts in RFG in other parts of the country, particularly if there is a broader MTBE ban.

Concerns have also been expressed about the adequacy of California refining capacity to meet demand for gasoline in the event of an MTBE ban. Demand is expected to increase to more than one million barrels per day by 2003, and capacity within the state will fall short by 6 to 10 percent. Historical U.S. ethanol production capacity was not sufficient to meet the overall demand nationwide if a waiver from the minimum oxygenate requirement is not granted, and thus significant expansion of ethanol capacity will be required. Alkylates must be imported from the Gulf Coast even if there is a waiver, and the price and availability of those blending components are also uncertain.[62]

According to an analysis by the Energy Information Administration:[63]

> *The patchwork quilt effect of individual state bans on MTBE will further complicate the gasoline supply and distribution system in the United States, which already handles more than 50 different types of gasoline as a result of state and federal regulations and market demand for different octane grades. One example is in the Northeast, where 65 percent of the gasoline supply is RFG. There is concern that by banning MTBE, New York and Connecticut have effectively created an island around New York City where RFG without MTBE is required. Areas with unique gasoline requirements are more vulnerable to supply disruptions and related price spikes.*

The CEC's analysis also stated that if MTBE is banned there may not be adequate refinery capacity or supplies of ethanol or alkylates to meet gasoline demand unless gasoline prices rise significantly to ration scarce supplies.[64] The author of the CEC analysis

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[60] U.S. Department of Energy, Energy Information Administration, "Issues in Focus: Phasing Out MTBE in Gasoline," *Annual Energy Outlook 2000*, 2001a.

[61] Schremp, "California Issues—Expanded Use of Ethanol and Alkylates," 2001; *Inside Cal/EPA*, "CEC Sees 6%–10% Gasoline Shortfall by 2003; Ethanol Main Culprit," 2001.

[62] Schremp, "California Issues—Expanded Use of Ethanol and Alkylates," 2001.

[63] U.S. Department of Energy, Energy Information Administration, "Legislation and Regulations: Banning or Reducing the Use of MTBE in Gasoline," *Annual Energy Outlook 2000*, 2001b.

[64] CEC, *Staff Report: Supply and Cost Alternatives to MTBE in Gasoline*, 1999a; See also Youn, "Ethanol: California Needs It, But Can It Get It?" 2001.

stated that the frequency and magnitude of price spikes in California could increase under an MTBE ban because of reduced flexibility in the system, a potential decline in import availability, and difficulty

Figure 5. Overview of Air Quality Impact of Switching from MTBE
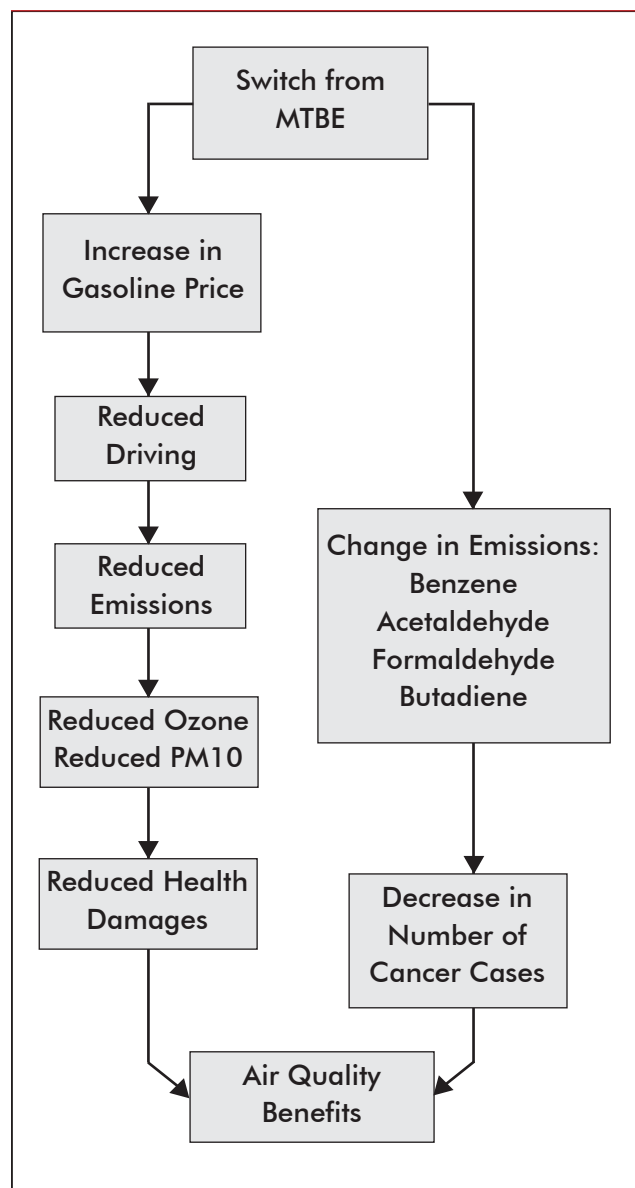
obtaining replacement supplies quickly. These factors could make the pump price to consumers significantly greater than the production cost increases projected for an MTBE phase-out.[65]

A study by Turner, Mason & Company[66] pointed out the high prices that could appear in the market if there is not adequate capacity to produce a gasoline without MTBE that still satisfies the RFG regulations without MTBE.[67] This study estimated the potential price increases if it is not possible to replace the gasoline volume lost when replacing MTBE with ethanol. Such a scenario would require reducing gasoline consumption approximately 6 percent below current levels. With short-term elasticities of demand between 0.1 and 0.2, the result would be an increase of 30 to 60 percent in gasoline prices—at current prices, between 50 cents and $1 per gallon.

4.5 Impacts on Air Quality

Air quality impacts resulting from a ban on MTBE include only those changes in air quality that occur when moving from RFG containing MTBE to either RFG containing ethanol or non-oxygenated RFG (see Figure 5 for an overview). The basic benefits of RFG satisfying the predictive model for improved ozone air quality are not considered because these air quality benefits are held to be the same whether MTBE, ethanol, or alkylates are used to manufacture the RFG.

However, different formulations of RFG have different impacts on air quality—even though all formulations satisfy the predictive model. There are both costs and benefits of banning MTBE. The removal of MTBE from gasoline will reduce emissions of formaldehyde and slightly reduce emissions of benzene and butadiene. However, use of ethanol will increase emissions of acetaldehyde.[68] Moreover, the higher cost (and thus price) of either ethanol RFG or non-oxygenated RFG will discourage gasoline consumption,

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[65] Schremp, "California Issues—Expanded Use of Ethanol and Alkylates," 2001.

[66] Cunningham et al., "Costs of Potential Ban of MTBE in Gasolines," 1999.

[67] *Ibid.*

[68] A reviewer suggested that ethanol may have the potential to increase ambient formaldehyde formation but that this effect is uncertain. Another reviewer suggested that ethanol has led to increased peroxyacetyl nitrate (PAN) concentrations in Brazil, although this effect is less likely (but possible) at the lower ethanol concentrations used in California (approximately 5 percent vs. 50 percent in Brazil). These potential air quality effects were not quantified in this analysis due to the significant uncertainty regarding their existence and magnitude.

leading to lower emissions of all gasoline combustion byproducts.

4.5.1 Effect of Higher Gasoline Costs

Higher gasoline prices reduce driving and provide air quality benefits that are not reflected in standard estimates of the effects of different gasoline formulations on air quality. Typically, standard estimates have used models that assume driving patterns that are the same across all fuel formulations considered. However, like most goods, the demand for gasoline is responsive to price, and as gasoline prices increase, the amount of gasoline consumed declines. To quantify the value of air quality improvement due to higher gasoline prices, it is necessary to (1) calculate the increase in the gasoline price at the pump due to the increased cost of manufacturing and distributing non-MTBE RFG; (2) calculate the reduction in driving resulting from the price increase; (3) calculate the reduction in air emissions attributable to the reduction in driving; and (4) place a monetary value on the emissions reduction. Since gasoline prices will increase nationwide if there is a California MTBE ban due to upward pressure on world oil prices, this analysis calculated air quality benefits for the entire country, though the vast majority of the benefits would occur in California.[69]

As previously discussed, this analysis presumed that refined products are produced at a fixed mark-up over the price of crude oil. Under these circumstances, the supply curve of refined products is perfectly elastic and any increase in costs is passed dollar for dollar to the price of refined products. This likely understates the impact on market prices and welfare losses when refineries operate close to capacity and when either capacity constraints or increasing marginal costs of refining create a rising supply curve, in which marginal costs exceed average costs. Under these circumstances, market prices will rise by more than the increase in average cost.

To calculate the reduction in emissions due to higher gasoline prices, reductions in gasoline consumption were presumed to have been achieved through reduced driving. The percentage reductions in gasoline consumption were based on a range of elasticities of demand for driving (vehicle miles traveled, or VMT, elasticities) as described in Appendix A. The VMT elasticities range from 0.1 to 0.2 and were based on nearly the full range found in the literature.

Percentage reductions in driving were multiplied by the on-road mobile source's (ORMS's) share of total emissions for each region.[70] This gave the percentage reduction in total emissions for each region. Multiplying the percentage reduction in emissions attributable to reduced driving by the total residual damages gave the reduction in residual damages attributable to reduced driving.[71]

To provide a comprehensive evaluation of the benefits of reduced driving, the marginal health damages expected under currently adopted programs must be estimated. Health effects and marginal damages from air pollution vary with the concentration of various pollutants in the atmosphere. California has adopted a set of programs that are deemed to be sufficient to achieve compliance with the National Ambient Air Quality Standards (NAAQS). Because of this, the NAAQS targets were taken to be the probable future levels of air pollution at which marginal health damages should be estimated. Unless emissions standards are made less stringent in light of the emissions reductions resulting from reduced driving, there would be a net drop in total emissions equal to those attributable to reduced driving. The resulting health benefits would be equal to the marginal health damages at planned levels of emissions multiplied by the reduction in emissions. The complex part of this analysis was

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[69] For non-California attainment regions there exists a range of possible residual damages. For this Monte Carlo analysis the damages were assumed to be distributed uniformly.

[70] Lyons et al., *Evaluating the Benefits of Air Pollution Control: Method Development and Application to Refueling and Evaporative Emissions Control*, 1994.

[71] The relevant calculation is Total Avoided Damage / Year = Marginal Damage / Person-Year × Percent Reduction in Emissions × Plan Level of Emissions × Population. The term "Percent Reduction in Emissions × Plan Level of Emissions" equals the incremental change in emissions. Therefore, the calculation is equivalent to the more familiar formula Total Avoided Damage / Year = Marginal Damage / Person-Year × Incremental Change in Emissions × Population.

estimating marginal health damages based on the current schedule for attaining the NAAQS and converting those to damages per ton of emissions.

Marginal damages in each region of the state, stated as dollars per parts per billion (ppb) per person per year, were found by estimating marginal damages at the SIP level of ozone concentrations. This calculation relied on a formula given in a report by Sierra Research (2000, p. 18):[72]

$$C(O) = \begin{cases} C_O \left[e^{a + b(O - O_t)} - 1 \right] \text{ for } O > O_t \\ 0 \qquad\qquad\qquad\quad \text{ for } O \le O_t \end{cases}$$

where O represents the ozone concentration, $C(O)$ represents annual per capita benefits per unit of ozone reduction at the specified ozone concentration, and a and b are parameters estimated from data on ozone concentrations and health effects.

Marginal damages state the amount by which damages per person would decline if ozone concentrations were reduced by one ppb. To calculate total residual ozone damages per person per year at the SIP level in each region, marginal damages were multiplied by the SIP level of ozone concentrations.

Base concentrations are concentrations measured or predicted in the absence of the California Air Quality Management Plan (AQMP).[73] Plan concentrations for the South Coast Air Basin (SCAB) were those predicted to be achieved through adoption of the 1991 AQMP. For the remaining regions, plan concentrations were set equal to the concentrations that would have

to be achieved by 1996 under the CAAA schedule for achieving the primary standard of 0.12 parts per million (ppm).[74] It was assumed that concentrations would be reduced linearly from the base value to the primary standard over the number of years allowed to achieve attainment.

Reductions in ozone also produce reductions in PM10 (particulate matter less than 10 microns in diameter), which has been linked to negative health effects. The calculation of this effect began with an estimate of the total quantified per capita health benefit of reducing PM10 using results from Sierra Research (2000) that were in turn based on the study published by Hall et al.[75, 76] This estimate was converted to the PM10 health benefit attributable to each ppb reduction in ozone concentration and used to supplement calculations of the direct ozone health benefits.[77]

Note that this analysis was extended to include the entire country since a change in crude oil prices would impact gasoline prices nationwide. The national benefits of reductions in air pollution due to reduced driving are estimated to be from $3.3 to $6.7 million per year for ethanol and from $5.5 to $11.1 million per year for non-oxygenated fuel. These air quality benefits from shifting to more costly fuels are quite small in relation to other components of the cost-benefit analysis due to the relatively small changes in driving that result, but they were included to be sure that all potential benefits of an MTBE ban were accounted for.

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[72] Lyons et al., *Evaluating the Benefits of Air Pollution Control: Method Development and Application to Refueling and Evaporative Emissions Control*, 1994.

[73] The base level of concentrations was taken from Table 5.3 in "Final 1991 Air Quality Management Plan," South Coast Air Quality Management District, 1991. Base concentrations for all other regions were 1985 design values taken from CARB's Web site, *www.arb.ca.gov*.

[74] *Whitman, Administrator of Environmental Protection Agency, et al. vs. American Trucking Associations et al.*, 2000.

[75] Hall, et al., "Valuing the Health Benefits of Clean Air," 1992.

[76] Lyons et al., *Evaluating the Benefits of Air Pollution Control: Method Development and Application to Refueling and Evaporative Emissions Control*, 1994.

[77] The complete computation is (Total Health Benefit from Reducing PM10 According to Hall Et Al. / Total Reduction in PM10 Concentration Assumed by Hall Et Al.) × (PM10 Reduction per Unit Reduction in Ozone Concentration). PM10 damages per person per year were calculated by multiplying PM10 damages per ppb of ozone per person per year by the plan level of ozone concentrations. These were multiplied by population in each region and added together to give total PM10 health benefits per year in each region. Regional California populations in 2000 were based on data for California from the 1996 *Statistical Abstract of the U.S.* published by the U.S. Census Bureau. Population estimates were adjusted to 2000 levels using population estimates and population growth rates estimated by CARB.

4.5.2 Effect of Changes in Air Toxics

The predictive model generates a reduction in PWT that is approximately the same for both ethanol-based and non-oxygenated fuels. However, similar PWT values can mask differences in individual toxics, and different speciations of air toxics can produce significantly different health risks. Therefore, this analysis compared results from the predictive model for each type of fuel and for four types of air toxics.

Changes in emissions for the four air toxics—benzene, butadiene, acetaldehyde, and formaldehyde—were calculated using the predictive model for each of the fuels. It was necessary to translate these changes in emissions to changes in concentrations of pollutants in the atmosphere, which allowed the use of CARB risk factors to estimate additional cancer deaths per ppb concentration. Changes in atmospheric concentration were then converted to changes in annual deaths (using the CARB risk factors). Averted annual deaths were valued by the EPA canonical number for the value of a statistical life.

The percentage changes in emissions for each of the four air toxics predicted by the Phase 3 predictive model are shown in Table 10. These percentages were calculated for both ethanol-based and non-oxygenated fuels relative to a reference fuel that was presumed to have emissions identical to that of MTBE RFG. Use of MTBE leads to higher emissions of formaldehyde, while use of ethanol leads to higher emissions of acetaldehyde. Both ethanol and alkylates lead to lower emissions of benzene and butadiene.

These percentage changes in emissions from motor vehicles had to be converted to percentage changes in concentrations of air toxics to estimate the changes in predicted cancer cases. This translation is illustrated in Table 11. Ambient concentrations and predicted cancer deaths from exposure to the reported ambient concentrations over a 70-year period were estimated

Table 10. Reductions in Air Toxics
(Percent Change Relative to Reference Fuel)

Compound	Ethanol	Non-Oxygenate
Benzene	−7.1	−3.6
Butadiene	−6.1	−2.9
Formaldehyde	−4.7	−10.7
Acetaldehyde	23.7	−9.1

by CARB.[78] The fraction of total emissions attributable to motor vehicles was estimated from various sources in the literature.[79] According to Sierra Research's (2001) analysis, 67 percent of benzene emissions are from motor vehicles. Ambient concentrations of acetaldehyde are a combination of the amount emitted directly as acetaldehyde and another portion that is formed secondarily from precursor emissions (e.g., from other reactive organic gas emissions such as ethyl peroxide and ethoxy radicals). Cars contribute to both categories. California state agencies estimate that cars and other mobile sources account for 15 to 32 percent of the total directly emitted acetaldehyde.[80] There is no information on the share that cars contribute to the secondary component of acetaldehyde. Accordingly, as an approximation, it is reasonable to presume that this share is comparable to the share of directly emitted acetaldehyde. As a result, 25 percent of the components of total ambient concentration of acetaldehyde will be increased by the amount that mobile source emissions are increased. Because of a lack of relevant data, all of the formaldehyde and butadiene emissions were presumed for this analysis to be attributed to motor vehicles. Obviously, this slightly exaggerated the benefits of an MTBE ban.

For unit risks, values were taken from CARB, based on California Office of Environmental Health Hazard Assessment (OEHHA) reports (See Table 11). Unit

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[78] Available at CARB's Web site, *www.arb.ca.gov/aqd/toxics/statesubstance.html*.

[79] In *Estimating Potential Cancer Cases Averted Due to CaRFG Following CARB/OEHHA Methodology* (2001), Sierra Research estimated that 67.45 percent of benzene emissions are from mobile sources. CARB and Office of Environmental Health Hazard Assessment, *Acetaldehyde as a Toxic Air Contaminant, Executive Summary*, 1993: According to the report, on-road mobile sources represented 15 to 32 percent of direct acetaldehyde emissions in California in 1987, and direct emissions represented 44 percent of total ambient concentrations. Mobile sources also contributed a significant (but not quantified) share of precursor emissions that are converted to the 56 percent of ambient concentrations that come from secondary acetaldehyde.

[80] CARB and Office of Environmental Health Hazard Assessment, *Acetaldehyde as a Toxic Air Contaminant, Executive Summary*, 1993.

Table 11. **Health Benefits of Air Toxic Reductions -**

	Benzene		Acetaldehyde		Formaldehyde		1, 3 Butadiene -	
	Ethanol	Non-Oxy-genated	Ethanol	Non-Oxy-genated	Ethanol	Non-Oxy-genated	Ethanol	Non-Oxy-genated
Concentration in 1999 (parts per billion) -	0.85	0.75	1.29	1.29	3.2	3.2	0.225	0.225
Estimated Risk (cancer cases per million over 70 years) -	79	79	6	6	24	24	85	85
Share of Emissions Attributable to Motor Vehicles -	0.67	0.67	0.25	0.25	1.00	1.00	1.00	1.00
Change in Emissions (percent) -	−7.10%	−3.60%	23.70%	−9.10%	−4.60%	−10.70%	−6.10%	−2.90%
Change in Annual Cancer Cases -	−1.82	−0.92	0.17	−0.07	−0.53	−1.24	−2.51	−1.19
Total Benefit	$9,106,710	$4,617,487	($860,098)	$330,249	$2,671,021	$6,213,028	$12,544,607	$5,963,829

risks purport to measure the increase in the lifetime probability of cancer due to a continuous exposure to a 1 ppb concentration of the carcinogen in question. Table 11 shows the calculations and estimates of the health damages attributable to air toxics emissions from each of the fuels.

In terms of reductions in the four major air toxics, health benefits from replacing MTBE with ethanol total $23.5 million annually and benefits from a non-oxygenated fuel total $17.1 million.

4.6 Water Quality Impacts

In evaluating the costs and benefits of using MTBE as a fuel oxygenate, careful evaluation of the water quality costs attributable to MTBE is critical. In performing this evaluation, the additional water quality costs that result from the presence of MTBE in gasoline must be distinguished from the total costs associated with any gasoline spill. One must also distinguish between sunk costs and future incremental costs. Future costs that result from past releases of gasoline containing MTBE are not alleviated by an MTBE ban. Therefore, to the degree there may be existing releases of gasoline and MTBE that will lead to future response costs, those costs are irrelevant to the question of whether MTBE should continue to be used in the future. It is only the

future costs associated with future releases of gasoline that can be alleviated by a current ban on MTBE, so only these costs are properly weighed against the cost of MTBE alternatives such as ethanol. Finally, it is important to recognize that ethanol and alkylates may also have adverse impacts on water quality.

4.6.1 Background on MTBE Impacts on Water Quality

MTBE may impact water sources via several pathways. The most common pathways are:

1) deposition of airborne MTBE molecules from emissions of vehicles burning gasoline that contains MTBE;

2) direct spills of "pure" MTBE, as may occur while MTBE is being transported to a refinery for blending into gasoline; and

3) releases of gasoline that contain MTBE.

While the first two pathways are of theoretical interest, the vast majority of MTBE that impacts water resources comes from releases of gasoline that contains MTBE. These gasoline releases can occur as a result of leaking underground storage tanks (LUSTs), leaking pipelines that contain gasoline, the release of unburned gasoline from boat motors, and direct spills of gasoline (as may occur from overfilling a vehicle tank or from an auto accident). The overwhelming majority of MTBE

contaminations of groundwater have been traced to LUSTs.[81]

Most of the MTBE that impacts water resources is blended in gasoline. Gasoline in ground and surface water is a problem in and of itself. While gasoline has many components that are undesirable in water, the primary focus of concern is typically benzene, toluene, ethylene, and the xylenes (the BTEX compounds). Benzene is a known human carcinogen; the EPA maximum permissible level of benzene in drinking water is 5 ppb and the State of California maximum contaminant level for benzene in drinking water is 1 ppb.[82]

Gasoline containing MTBE may impose costs in addition to those that would occur had the gasoline not contained MTBE. The incremental impact of MTBE on water resources, in addition to that of the BTEX components, is a function of several chemical properties of MTBE. These include:

- MTBE does not degrade as rapidly as the BTEX compounds. Therefore, MTBE may persist longer in the environment than BTEX.

- Because MTBE does not degrade as rapidly as BTEX, MTBE also may travel further than BTEX in groundwater, leading to a larger area of contamination (or a longer "plume") and greater probability that a drinking water source may be affected.

- MTBE does not sorb (bind) to soil (or other carbon substances) as well as BTEX does. This characteristic may allow MTBE released into groundwater to travel further than the BTEX components of gasoline.[83] In addition, the relative lack of binding to carbon may make MTBE more difficult to remove from groundwater when using granulated activated carbon (GAC) filtration water treatment systems.[84]

- On the other hand, because MTBE does not bind well to soil, it does not get "hung up" in the soil as BTEX can and therefore may be easier to remove from the subsurface.[85]

- MTBE is more soluble in water than BTEX, which means that more MTBE than BTEX dissolves in a given quantity of water. This may lead to higher observed concentrations of MTBE than BTEX. This may also make MTBE more difficult to remove from water when using technologies such as air stripping.[86]

- The threshold at which MTBE can be tasted or smelled is low.[87] Because of this aesthetic concern, even water with relatively low levels of MTBE may require remediation.[88]

4.6.1.1 Mobility and Biodegradability of MTBE

The primary perceived threat to water resources posed by MTBE is related to the belief that MTBE does not degrade (or degrades much more slowly than the BTEX compounds) and is much more mobile in groundwater than the BTEX compounds. Both of these characteristics are presumed to lead to larger and more lasting areas of groundwater contamination from

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[81] See Fogg et al., "Impacts of MTBE on California Groundwater," 1998.

[82] See the Web site of the San Francisco Public Utilities Commission, *www.sfwater.org*.

[83] See "MTBE Fact Sheet #2," U.S. EPA, 1998.

[84] *Ibid*.

[85] See "MTBE Fact Sheet #2," U.S. EPA, 1998; Thomson, "Prospects for Natural Attenuation of MTBE," 2000.

[86] See "MTBE Fact Sheet #2," U.S. EPA, 1998; Keller et al., "Cost and Performance Evaluation of Treatment Technologies for MTBE-Contaminated Groundwater," 1998.

[87] California adopted a secondary maximum contaminant level for MTBE in drinking water of 5 ppb, based on taste and odor considerations. EPA issued a drinking-water advisory in December 1997 stating that concentrations of MTBE in the range of 20–40 ppb of water or below will probably not cause unpleasant taste and odor for most people, recognizing that human sensitivity to taste and odor varies widely (California Environmental Protection Agency, *MTBE (methyl tertiary-butyl ether) and Underground Storage Tanks*, 1997). The California health-based threshold for MTBE is 13 ppb. EPA has stated that there is little likelihood that MTBE concentrations between 20 and 40 ppb in drinking water would cause negative health effects. Therefore, while the concern over benzene in groundwater is based on health considerations, concern over MTBE is largely based on aesthetic considerations.

[88] The California health-based threshold for benzene is 1 ppb, lower than the aesthetics-based threshold for MTBE. However, in RFG made with MTBE, approximately 10–15 percent of the gasoline by volume may be comprised of MTBE. For conventional gasoline, only about 1.6 percent of the gasoline by volume is comprised of benzene.

MTBE-containing gasoline than would result from gasoline that does not contain MTBE. Therefore, the degree to which MTBE is recalcitrant to biodegradation and the extent to which MTBE causes the area of groundwater contamination to increase are critical parameters in the evaluation of the potential impact of MTBE on water resources.

Some research finds that plume lengths when MTBE is present are actually shorter than when MTBE is not present.[89] Other empirical research suggests that plumes from gasoline containing MTBE are, on average, 18 percent longer than plumes that would result from conventional gasoline.[90] Other research suggests that, on average, MTBE plumes may be about twice as long as plumes from conventional gasoline.[91]

Clear scientific results for these issues are not available, and existing data on the rate at which MTBE will biodegrade in the environment and the extent to which MTBE increases the length of contaminant plumes from LUSTs vary widely. However, research to date does indicate that:

1) at least under some conditions, MTBE does degrade in the environment;[92]
2) MTBE does not always, or even usually, increase the length of LUST plumes; and
3) if MTBE does increase LUST plume lengths, this effect is not always significant.

Indeed, the most recent evidence seems to suggest that MTBE biodegrades more rapidly than originally expected and that MTBE plumes are not as long as expected. To the degree that MTBE does degrade in the environment and does not significantly increase the length of plumes from LUSTs, the incremental threat of MTBE to groundwater is small.

Because of the considerable uncertainty surrounding the impact, mobility, and biodegradability of MTBE—and the import of these issues on the associated incremental impact of MTBE on groundwater— this analysis allowed the incremental effect of MTBE on groundwater to vary over a wide range of values in the cost-benefit model. Even under the worst-case scenario (where the incremental water quality costs of MTBE were assumed to be high), the incremental water quality costs of MTBE are much less than the increase in costs to manufacture RFG with ethanol rather than with MTBE.

4.6.2 Background on Ethanol's Impacts on Water Quality

While MTBE's potential impact on water quality and the cost associated with that impact have been widely discussed, it is becoming more accepted that ethanol also adversely impacts water quality. However, despite the widespread use of ethanol as a fuel oxygenate in other parts of the United States, there has been comparatively little analysis of the impact of ethanol on groundwater and on the costs of responding to releases of ethanol-containing gasoline to groundwater.

Ethanol itself appears to pose little concern in water. The concentrations of ethanol that would result from a spill of RFG made with ethanol are likely to be lower than any level of concern.[93] However, there

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[89] Reisinger et al., "MTBE and Benzene Plume Behavior: A Comparative Perspective," 2000. These data may understate the effect of MTBE on plume length. Some of the plumes in the data may have resulted from a LUST where the leak began years before MTBE was added to gasoline. In this case, the fact that MTBE is not further ahead of the BTEX components of the gasoline may be because the BTEX components had a head start.

[90] *Ibid.*

[91] See van de Griend and Kavanaugh, "Evaluation of the Effects of Methyl tert-Butyl Ether on Leaking Underground Fuel Tank Investigation and Remediation Programs," 1996, which reports that MTBE plumes are from 100 to 300 percent as long as BTEX plumes; and California Regional Water Quality Control Board, Los Angeles Region, *Regional Board MTBE Study Report: Estimation of MTBE Plume Length Using Domenico Analytical Model*, 1999, which reports MTBE plumes twice as long as BTEX plumes.

[92] See van de Griend and Kavanaugh, "Evaluation of the Effects of Methyl tert-Butyl Ether on Leaking Underground Fuel Tank Investigation and Remediation Programs," 1996, which indicates increasing reports—as of 1996—of biodegradation of MTBE; *ENN News*, "Gas Wars: Microbes Fight Water and Soil Pollution," 2000; Ramsden, "MTBE Bioremediation Studies: Are We Learning Anything?" 2000; and Thomson, "Prospects for Natural Attenuation of MTBE," 2000.

[93] Malcolm Pirnie, Inc., *Evaluation of the Fate and Transport of Ethanol in the Environment*, 1998. The taste threshold for ethanol is reported to be near 50 ppm. No health-based threshold appears to exist for ethanol in drinking water, but commentators seem to agree that health effects are unlikely at any ethanol concentration likely to result from a LUST.

is a growing body of evidence that suggests that the presence of ethanol inhibits the degradation of benzene in groundwater. As a result, when gasoline that contains ethanol is released into groundwater, resulting benzene plumes can be longer and more persistent than plumes resulting from releases of conventional gasoline. Research by the ethanol and MTBE industries, as well as by the University of California, suggests that the presence of ethanol in gasoline delays the degradation of benzene and lengthens benzene plumes by about 25 percent.[94] Other studies find a larger effect of ethanol on benzene plume length—with ethanol-containing gasoline plumes estimated to be as much as twice as long as plumes from conventional gasoline.[95] This research also appears to suggest that concentrations of benzene will be greater as well. However, no concrete estimates appear to be available on the magnitude of this impact.

The effect on remediation costs of a greater plume length resulting from the presence of ethanol may be the same (at least qualitatively) as when a longer plume results from MTBE. Unfortunately, at this time little conclusive research has been completed on the relative magnitude of the effects of MTBE and ethanol on plume lengths or of the effect of those factors on site remediation costs. Some data suggest that the relative effects of MTBE and ethanol on plume length may be approximately equal. However, other data suggest that the effect of MTBE on plume length may be much greater than the impact of ethanol. Moreover, whatever the effect on plume length, the presence of MTBE may increase water remediation costs (per gallon treated), an effect not anticipated for ethanol. Therefore, it was appropriate to structure the model so that the impact of MTBE on remediation costs was greater than that of ethanol. The degree to which the MTBE impact exceeds the ethanol impact was allowed to vary but the model was generally structured such that the impact of ethanol on water quality was likely to be small relative to the impact of MTBE on water quality.

4.6.3 Background on the Impact of Alkylates on Water Quality

Non-oxygenated RFG may also have an impact on water quality. This fuel formulation would contain significantly more toluene. One researcher has suggested that the increase in above-ground remediation costs due to the increased level of toluene in non-oxygenated RFG could be approximately 10 percent.[96] The available literature does not partition total remediation costs into above-ground versus below-ground costs. Accordingly, this analysis imposed the conservative assumption that non-oxygenated RFG would not have any incremental impact on water quality.

4.7 The Impact of MTBE and Ethanol on Water Quality

The estimated water quality impacts of MTBE and ethanol are comprised of several cost components:

1) The cost to investigate and remediate LUST sites;
2) The cost to investigate and remediate leaking pipelines;
3) The cost to treat or replace drinking water sources impacted because of the presence of MTBE or ethanol; and
4) The cost to monitor and treat surface water contaminated with MTBE.

The impacts from each of these components were estimated separately. Of these components, the most significant was the cost to investigate and remediate LUST sites.

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[94] Ulrich, *The Fate and Transport of Ethanol-Blended Gasoline in the Environment: A Literature Review and Transport Modeling*, 1999; McNab et al., "Chapter 4: Screening Model Evaluation of the Effects of Ethanol on Benzen Plume Lengths," 1999; Malcolm Pirnie, Inc., *Evaluation of the Fate and Transport of Ethanol in the Environment*, 1998.

[95] Schirmer et al., "The Potential Impact of Alcohol as a Gasoline Oxygenate on BTEX Degradation at Spill Sites," 1999.

[96] Keller et al., *An Integral Cost-Benefit Analysis of Gasoline Formulations Meeting California Phase 2 Reformulated Gasoline Requirements*, 1998.

4.7.1 LUST Sites

The calculation of the incremental impact of MTBE and ethanol on the cost to investigate and remediate LUST sites is presented in Figure 6.

The calculation began with an estimate, for the relevant time period, of the number of underground storage tanks containing gasoline. This population of tanks was then partitioned between upgraded and non-upgraded tanks. This distinction is important, since upgraded tanks are expected to fail (i.e., leak) with less frequency than non-upgraded tanks.[97] The proportion of tanks that fall into the upgraded category has been increasing over time.[98]

Based on the frequency of tank failure (leakage) and the number of upgraded and non-upgraded tanks, the number of new LUST sites in each year can be calculated. Some but not all of these LUSTs would impact groundwater. The probability that a LUST impacts groundwater is independent of whether the gasoline contains MTBE or ethanol.[99] All LUST sites that impact groundwater must be investigated. Investigation is a one-time cost, and this cost occurs in the year the tank leak is detected.

Investigation costs for LUST sites where the tank contained gasoline with MTBE may be greater than if the tank contained only "conventional" gasoline. Investigation costs were assumed to be greater because plumes from tanks that contain MTBE may be longer. Longer plumes may generally take more effort to fully define and characterize (more wells may have to be drilled, etc.).[100] The degree to which investigation costs are increased is uncertain, and this analysis assumed that the increase in costs could range from 0 to 47 percent.

Ethanol appears to increase the length of benzene plumes. Therefore, if MTBE increases site investigation costs because MTBE plumes tend to be longer, the same should be true for ethanol. Accordingly, the impact of both ethanol and MTBE on investigation costs was modeled consistently. This analysis relied on existing estimates of the impact of MTBE on site investigation costs. The corresponding impact of ethanol on site investigation costs was treated as proportional to the relative increases in plume length from ethanol and MTBE. For instance, available data suggest that the degree to which MTBE lengthens a LUST plume can be from 18 to 350 percent. Available data also suggest that ethanol may increase plume length by 25 to 250 percent (although the lower estimate is probably the more accurate). Therefore, the impact of ethanol on site investigation costs would range from equal to the MTBE impact (since 18 percent and 25 percent are approximately equal) to approximately one-twelfth the MTBE impact (since 25 percent is approximately one-twelfth of 350 percent).[101]

All LUST sites that impact groundwater require some form of remediation. While the costs of remediation at any specific site are driven by unique, site-specific factors, it is useful to distinguish between two types of sites: (1) those addressed by natural attenuation; and (2) those that are actively remediated. Sites addressed by natural attenuation require only source removal and monitoring. Sites addressed by active remediation employ some active form of removal of the gasoline components from the groundwater. Typically,

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[97] Couch and Young, *Leaking Underground Storage Tanks (USTs) as Point Sources of MTBE to Groundwater and Related MTBE-UST Compatibility Issues*, 1998.
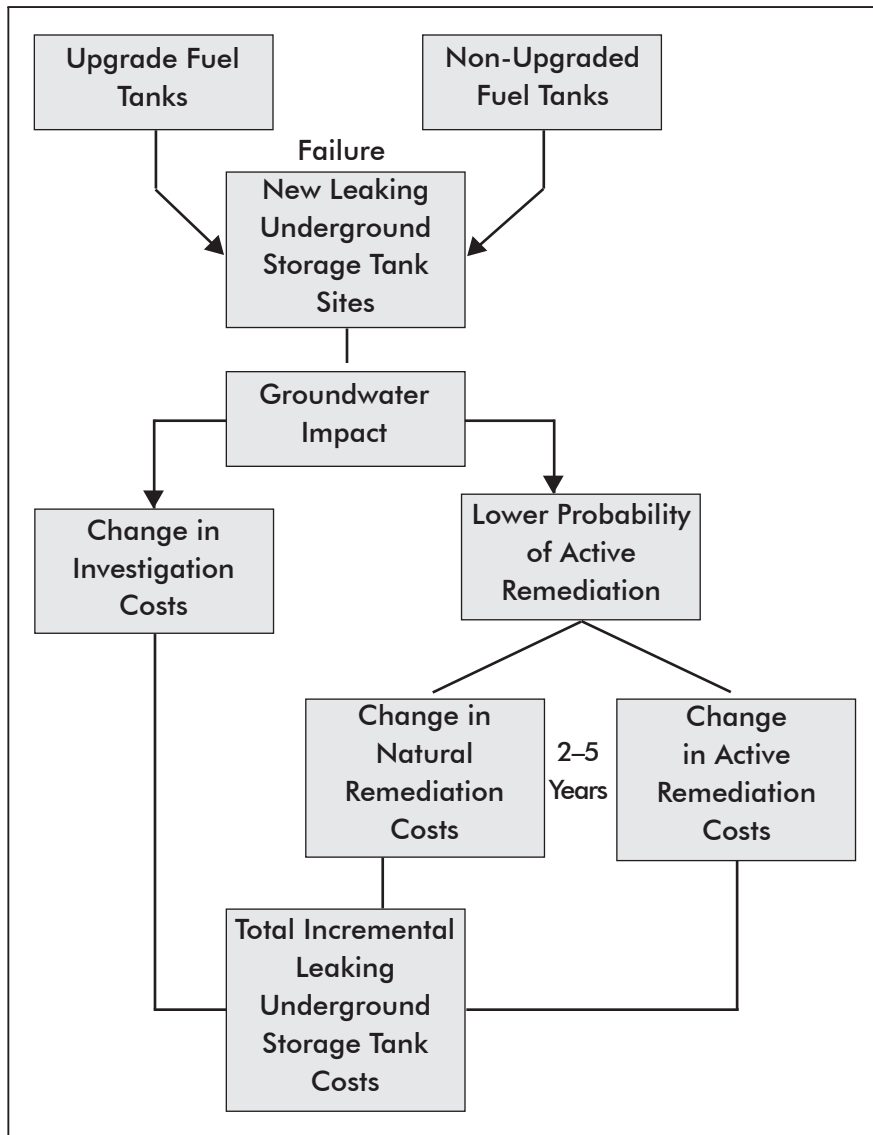
[98] Moreover, EPA's underground storage tank upgrade program—which required the upgrade or closure of most gasoline-containing tanks by 1998—resulted in closure of approximately half the underground storage tanks in California. Therefore, not only is a greater percentage of the tank population becoming less prone to leaks, but the total number of tanks that may leak is declining through time as well.

[99] The analysis ignores the sites that do not impact groundwater. While these sites do have to be cleaned up, the cost of cleanup is not sensitive to whether the gasoline contains MTBE or ethanol. See, for instance, Keller et al., *An Integral Cost-Benefit Analysis of Gasoline Formulations Meeting California Phase 2 Reformulated Gasoline Requirements*, 1998. Therefore, there is no incremental impact of MTBE or ethanol at these sites.

[100] Note, however, that there is some reason to believe that there may be little impact on site investigation costs as the size of the plume increases. The use of sophisticated modeling allows the edge of the plume to be predicted with some accuracy. The presence of MTBE and or ethanol can be incorporated into these models, thus obviating the need for a grid search pattern of well drilling.

[101] The basis for the specified ranges may be found in "MTBE Fact Sheet #2," U.S. EPA, 1998.

Figure 6. Change in Leaking Underground Storage Tank Remediation Costs due to Switching from MTBE -

Keller et al. (1998) hypothesized that the presence of MTBE in a LUST plume will make it more likely that the site will have to be actively remediated. The rationale for this hypothesis is not entirely clear, but it may stem from an assumption either that plumes with MTBE will be longer or that MTBE itself generates greater concerns about groundwater, perhaps because it degrades more slowly. Note, however, that both of these factors—longer plume lengths and slower degradation of the contamination—also occur (although perhaps to a lesser degree) when ethanol is present in the plume. Therefore, to the degree that the presence of MTBE increases the probability that a LUST site must be actively remediated, the same should be true for ethanol (although, again, perhaps to a lesser degree).

There is little empirical evidence to suggest that plumes from gasoline that contains MTBE or ethanol result in a higher probability that a LUST site will require remediation. Some remediation engineers consulted for this study have concluded that the presence of MTBE is not a driving factor in whether a site is actively remediated. Moreover, a survey of the regional water quality control boards in California indicates that MTBE is not a clear factor in determining whether the site will be actively remediated.[102] None of the water quality control boards appears to have either a formal policy or written guidance on which LUST sites must be actively remediated versus addressed by natural attenuation. Approximately

this is air stripping or carbon filtration treatment. The cost of addressing a site by active remediation is significantly higher than the cost of addressing a site by natural attenuation. If the presence of MTBE or ethanol increases the probability that a site must be actively remediated rather than naturally attenuated, response costs increase (even if there is no increase in the actual cost of actively treating the site).

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[102] The nine California regional water quality control boards were surveyed in March 2001. Region 6 representatives could not be reached, and Region 9 representatives declined to participate. Of the remaining seven regions, three regions reported that the presence of MTBE may increase the likelihood that the site would need to be actively remediated and the remaining four regions reported that the presence of MTBE by itself was not a decisive factor in deciding whether a site needed to be actively remediated.

half the boards surveyed thought that the presence of MTBE would increase the likelihood that the site would have to be actively remediated, while the other half thought the presence of MTBE would have no effect. Given this uncertainty about the impact of MTBE and ethanol on the remediation approach at a site, it is possible that MTBE or ethanol could have no effect on whether the site must be actively remediated. This analysis also allowed for the possibility that MTBE or ethanol would make it as much as twice as likely that the site would have to be actively remediated. It was presumed that sites containing ethanol are less likely to be actively remediated than those containing MTBE.

Costs at sites addressed by natural attenuation are independent of whether the site contains MTBE or ethanol. However, response costs at sites that are actively remediated can be higher if the gasoline contains MTBE or ethanol. Response costs may increase because the plume is longer, an effect that would result from the presence of either MTBE or ethanol. However, response costs may also increase because the methods used to remove benzene from water are not as effective at removing MTBE. This may lead to an increase in remediation costs; such impacts would be specific to MTBE and not occur when ethanol is present (since ethanol typically does not have to be removed from the groundwater). The impact of MTBE or ethanol on remediation costs is uncertain. As a result, this analysis allowed for the possibility that the increase in costs could range from 25 to 100 percent (of the costs that would be incurred if the LUST plume contained only conventional gasoline). Moreover, the analysis assigned a larger impact on remediation costs to MTBE than to ethanol.

Recent research suggests that removing MTBE from groundwater may not be as difficult as first thought. Remediation technologies and practices in the mid-1990s were well optimized for the removal of BTEX but not for MTBE since MTBE had not been a focus of concern at most LUST sites. With increased concern over the removal of MTBE, more effective treatment technologies were developed.[103] Moreover, some characteristics of MTBE may make it easier to remediate. Specifically, MTBE does not bind to soil as well as the BTEX compounds do. This means that MTBE is in some sense easier to remove from the subsurface since it clings less tightly to the soil. BTEX compounds, on the other hand, are often tightly bound to the soil. As contaminated groundwater is pumped, treated, and re-injected, BTEX continues to release from the soil and re-contaminate the water. This "rebound" effect is reported to be absent (or less severe) for MTBE.[104]

The estimated annual benefit of replacing MTBE with ethanol, in terms of reduced water quality costs associated with gasoline released from LUSTs, ranges from nearly zero to $522.7 million with an expected value of $95.1 million. The estimated annual benefit of replacing MTBE with alkylates, in terms of reduced water quality costs associated with gasoline released from LUSTs, ranges from nearly zero to $585 million with an expected value of $131.1 million. The range of incremental costs of MTBE is relatively wide due to the uncertainty of the impact of MTBE on groundwater. However, even under the worst-case scenario—where the incremental impact of MTBE is assumed to be very large—the costs of switching to ethanol or alkylates still exceed the water quality costs of MTBE.

4.7.2 Wells

LUST plumes may result in costs other than those associated with addressing and remediating the site. If gasoline constituents from the LUST reach a drinking water well, treatment (or replacement) of the well may be required. Both MTBE and ethanol may increase the likelihood that a LUST plume will reach a drinking water well since both chemicals may result in longer plumes. The calculation of the incremental impact of MTBE and ethanol on the cost to remediate wells impacted by LUST plumes is presented in Figure 7.

[103] See, for instance, Keller et al., *Advances in Treatment to Remove MTBE*, 1999; and U.S. EPA, "MTBE Fact Sheet #2," 1998, which states that at many sites MTBE will not have any incremental impact on remediation costs and that at 75 percent of sites the impact will be less than 50 percent.

[104] See, for instance, Thomson, "Prospects for Natural Attenuation of MTBE," 2000.

Figure 7. Incremental Change in Well Remediation Costs due to Switching from MTBE -
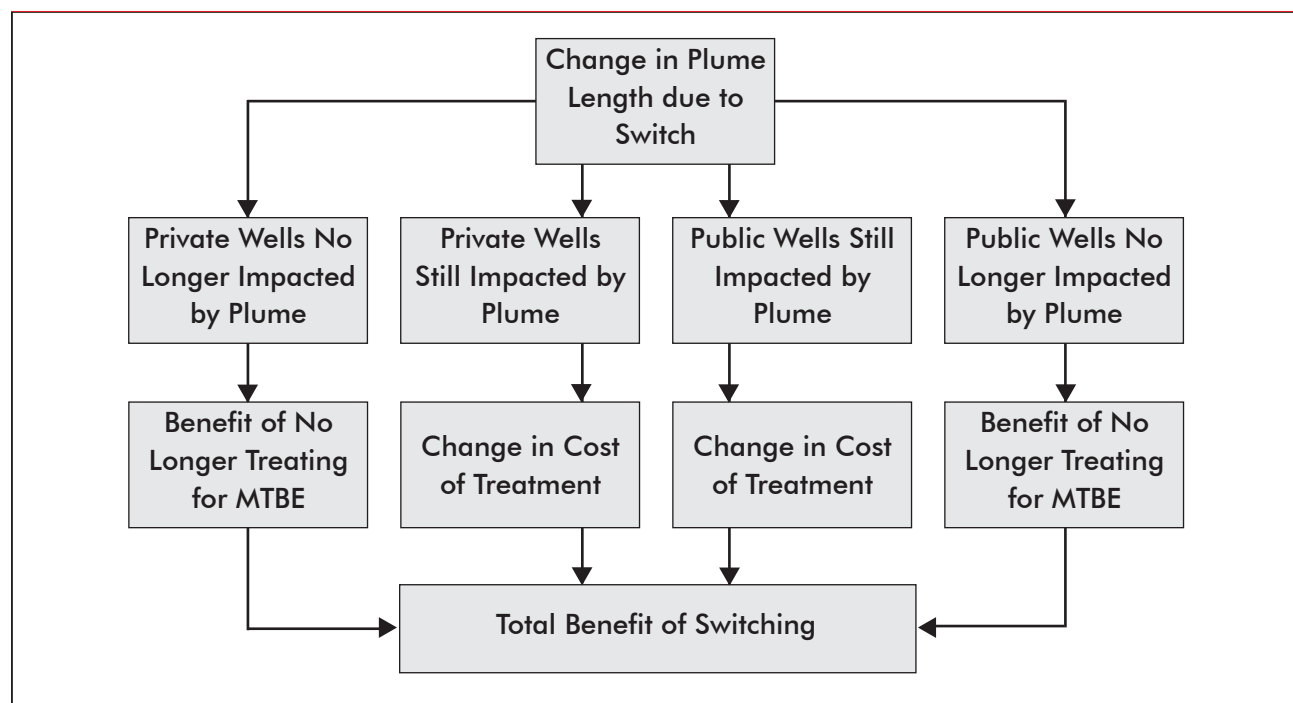
In estimating the number of wells that may register a detectable level of MTBE, the population of wells was decomposed across public and private wells.[105] Public wells are fewer in number and tend to be drilled deeper. Therefore, they are less likely to show detectable levels of gasoline constituents from a LUST plume. However, a public well typically pumps more water than a private well, so public wells are more costly to treat or replace. If a well registers levels of benzene above the regulatory action threshold (1 ppb in California), treatment will be required–regardless of whether MTBE is present. However, the presence of MTBE may increase the cost of treatment of these wells since MTBE may be more difficult to remove from groundwater than benzene.[106] Similarly, the presence of ethanol may retard the degradation of benzene and lead to higher benzene concentrations and larger benzene plumes–thus leading to higher treatment costs.
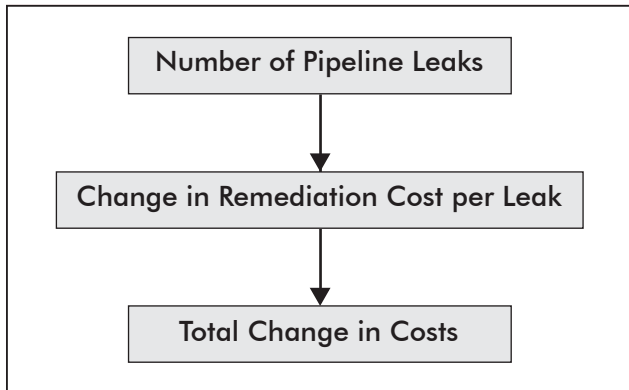
If the presence of MTBE or ethanol lengthens a plume, wells that otherwise would not have been reached may be contaminated. In this case, the entire cost of treating the well can be attributed to MTBE or ethanol. It is understood that most wells that have detectable levels of MTBE also have detectable levels of benzene.[107] For the "MTBE-only" wells, the total cost of treatment was attributed to MTBE. For the remainder of wells (those that have detectable levels of both MTBE and benzene), treatment costs may increase because of the presence of MTBE. Consistent

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[105] The estimate upon which this analysis relies (from University of California) is an estimate of the *cumulative* number of wells impacted by MTBE as of 1998. MTBE has been used in gasoline in California since the 1980s, although its use increased substantially in 1996 with the phase-in of CARB Phase 2 RFG. Therefore, the cumulative number of wells impacted by MTBE in 1998 likely overstates the number of *additional* wells that would be impacted in a single year. On the other hand, since the widespread use of MTBE in gasoline only began about two years before the University of California analysis was conducted, and since MTBE plumes may continue to grow more than two years after the initial release, it may be the case that the number of wells that will eventually be impacted by past releases of MTBE is greater than the number of wells impacted as of 1998.

[106] As discussed previously, however, there are some characteristics of MTBE that would make it easier to remove from groundwater than benzene.

[107] See, for instance, *MTBE Treatment Case Studies*, U.S. EPA's Office of Solid Waste and Emergency Response, 2001b.

Figure 8. Incremental Change in Pipeline Spill Costs due to Switching from MTBE

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┌─────────────────────────────────────┐
│                                     │
│   ┌─────────────────────────────┐   │
│   │   Number of Pipeline Leaks  │   │
│   └─────────────────────────────┘   │
│                 │                   │
│                 ▼                   │
│   ┌─────────────────────────────┐   │
│   │ Change in Remediation Cost  │   │
│   │        per Leak             │   │
│   └─────────────────────────────┘   │
│                 │                   │
│                 ▼                   │
│   ┌─────────────────────────────┐   │
│   │    Total Change in Costs    │   │
│   └─────────────────────────────┘   │
│                                     │
└─────────────────────────────────────┘
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with the modeling of LUSTs, the incremental impact of MTBE on treatment costs for wells would range from 25 to 100 percent.

Ethanol may increase the number of wells that show detectable levels of benzene, thereby increasing total treatment costs. This analysis presumed that the impact of ethanol on the number of wells that need to be treated would be from 7.45 to 100 percent of the impact of MTBE.

The estimated annual benefit of replacing MTBE with ethanol, in terms of reduced water quality costs associated with impacted drinking water wells, ranges from $1.8 to $97.1 million with an expected value of $24.9 million. The estimated annual benefit of replacing MTBE with alkylates, in terms of reduced water quality costs associated with impacted drinking water wells, ranges from $3.9 to $111.6 million with an expected value of $30.7 million.

4.7.3 Pipelines

Pipelines that contain gasoline may leak. For the reasons previously discussed, the presence of MTBE or ethanol in such releases may increase the cost to address them. The modeling of the incremental impact of MTBE or ethanol from pipeline gasoline releases is presented in Figure 8. The approach is similar to that presented for LUSTs.

The Office of the State Fire Marshall reported that the average number of gasoline releases in California
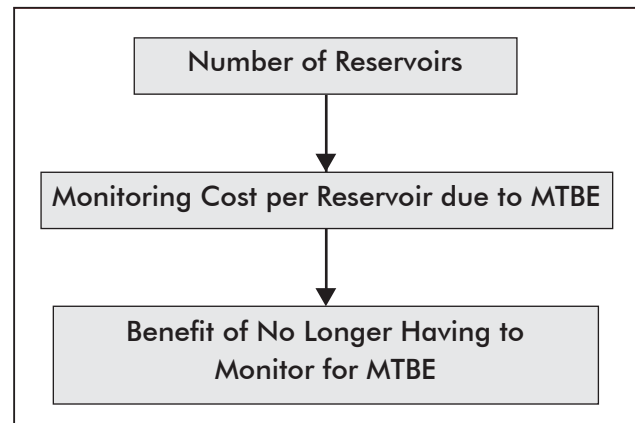
resulting from pipeline leaks has ranged from 5 to 10 releases per year.[108] If MTBE is present in the leaked gasoline, response costs could increase. Consistent with other components of the model, this increase would range from 25 to 100 percent over and above the cost of addressing a spill of conventional gasoline alone. The presence of ethanol may also impact the cost of addressing the spill. Consistent with modeling of the effect of ethanol elsewhere in the analysis, the incremental impact of ethanol is between 7.45 and 100 percent of the incremental cost attributable to MTBE.

The estimated annual benefit of replacing MTBE with ethanol, in terms of reduced water quality costs associated with pipeline leaks of gasoline, ranges from nearly zero to $1.5 million with an expected value of $0.4 million. The estimated annual benefit of replacing MTBE with alkylates, in terms of reduced water quality costs associated with pipeline leaks of gasoline, ranges from nearly zero to $1.8 million with an expected value of $0.7 million.

4.7.4 Surface Water

Gasoline contamination of surface water is due primarily to the release of uncombusted gasoline from boat motors. If the gasoline contains MTBE, there may be a greater concern about these releases because traces of MTBE could be selectively dissolved into the water body. Certain surface reservoirs in California are

Figure 9. Incremental Change in Surface Water Costs due to Switching from MTBE

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┌─────────────────────────────────────┐
│                                     │
│   ┌─────────────────────────────┐   │
│   │    Number of Reservoirs     │   │
│   └─────────────────────────────┘   │
│                 │                   │
│                 ▼                   │
│   ┌─────────────────────────────┐   │
│   │  Monitoring Cost per        │   │
│   │  Reservoir due to MTBE      │   │
│   └─────────────────────────────┘   │
│                 │                   │
│                 ▼                   │
│   ┌─────────────────────────────┐   │
│   │  Benefit of No Longer Having│   │
│   │  to Monitor for MTBE        │   │
│   └─────────────────────────────┘   │
│                                     │
└─────────────────────────────────────┘
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[108] SRI Consulting/SRI International, *A Review and Evaluation of the University of California's Report, "Health and Environmental Assessment of MTBE,"* 1998.

reportedly being monitored for MTBE but no surface waters are reportedly being treated for MTBE. Modeling of the incremental impact from MTBE on surface water is presented in Figure 9.

Due to heightened concern over MTBE, this analysis assumed that all surface water reservoirs in California that allow boating and also are used as drinking water sources are periodically monitored for MTBE.[109] The total number of reservoirs to be monitored was between 100 and 150, and the annual cost of monitoring per reservoir was $10,000 to $25,000.[110] The total cost of this monitoring was attributed to MTBE. No incremental cost was attributed to MTBE

for the treatment of surface water since to date there does not appear to be any such treatment occurring. Nor was any incremental cost attributed to ethanol for surface water monitoring or treatment.

The estimated annual benefit of replacing MTBE with ethanol, in terms of reduced water quality costs associated with gasoline contamination of surface water, ranges from $1 to $3.7 million with an expected value of $2.2 million. The estimated annual benefit of replacing MTBE with alkylates, in terms of reduced water quality costs associated with gasoline contamination of surface water, ranges from $1 to $3.7 million with an expected value of $2.2 million.

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[109] This assumption was contained in the 1998 University of California analysis of MTBE. See Keller et al., 1998. It is not clear, in fact, that all reservoirs in California that both supply drinking water and allow boating are routinely monitored for MTBE. To the degree that some reservoirs are not so monitored, the resulting cost of MTBE would be less and the benefit of MTBE over ethanol greater.

[110] See Keller et al., *An Integral Cost-Benefit Analysis of Gasoline Formulations Meeting California Phase 2 Reformulated Gasoline Requirements*, 1998a.

5. CONCLUSION

Even though the pendulum has now swung toward an emphasis on water quality concerns, sound public policy demands careful analysis of proposals to restrict or ban the use of MTBE. Similar to implementation of the CAAA, such a ban will clearly have significant economic consequences—some positive and some negative. Assessing whether such a policy would have net social benefits requires a comprehensive and internally consistent cost-benefit analysis. This analysis examines all of the consequences of a ban of MTBE in California and includes significant categories of economic impact that have largely been neglected in the debate over MTBE. These impacts include the cost to taxpayers resulting from a dramatic increase in the use (and therefore subsidization) of ethanol, the cost of increased oil imports associated with removal of MTBE from gasoline, the effects that changes in gasoline prices associated with removal of MTBE would have on gasoline consumption and thus on automobile emissions, and the potential effect of the various alternatives to MTBE on water quality. A comprehensive cost-benefit analysis demonstrates that (1) modeling all the crucial market interactions is necessary to capture the relevant costs and benefits; (2) it is important to distinguish incremental and sunk costs carefully and to recognize that sunk costs are irrelevant to decisions looking forward; (3) the incremental effects of the decision at issue must be used to structure the data and analysis; and (4) it is not always possible to tell before doing the analysis what can safely be ignored. All previous attempts to characterize the costs and benefits of an MTBE ban failed to follow at least one of these methodological recommendations and, consequently, obtained results that were either incorrect or misleading.

Overall, this analysis indicates that continued use of MTBE in California gasoline has clear and significant benefits relative to the use of either ethanol or non-oxygenated RFG. The increased annual cost resulting from a ban of MTBE in California when ethanol replaces MTBE ranges from $0.34 to $1.01 billion with an expected value of $0.86 billion. When non-oxygenated RFG replaces MTBE, the annual increased cost ranges from $0.39 to $1.05 billion with an expected

value of $0.88 billion. It is important to note that, even though some of the costs associated with banning MTBE are subject to significant uncertainty, the use of MTBE stochastically dominates both the ethanol and non-oxygenated RFG options. That is, even if we assume the worst case for MTBE and the best case for the other options, it is still the case that banning MTBE will lead to an increase in the total costs associated with gasoline use in California.

The results of this study indicate that the total increase in gasoline production costs resulting from replacement of MTBE with ethanol in California ranges from $0.89 to $1.05 billion with an expected value of $1.01 billion. Should a waiver be granted allowing non-oxygenated fuel to be used in California, the increase in gasoline production costs would be $0.97 to $1.09 billion with an expected value of $1.07 billion. All costs are reported on an annual basis. The fuel cost impacts of replacing MTBE with ethanol, for example, are driven higher by (1) the ethanol tax subsidy (representing approximately 37 percent of the increase); (2) refinery costs, oil import costs, and losses in consumer surplus (representing approximately 63 percent of the increase); and (3) losses from the increase in natural gas demand (representing approximately 15 percent of the sum of components (1) and (2)).

Surprisingly, changes in air quality do not contribute a significant cost or benefit compared to other cost categories. The CAAA requires specific reductions in emissions for the two ozone precursors, NOx and reactive HCs, from RFG. Under federal and CARB regulations, all legal fuels must achieve at least as great a reduction in NOx and reactive organic gases as does a specified reference fuel. Therefore, this analysis estimates that no change in emissions of ozone precursors would result from replacement of MTBE by ethanol or alkylates. The direct air quality effects that can be expected to result from such substitution are (1) reductions in driving due to higher fuel costs, and (2) changes in emissions of air toxics such as formaldehyde and acetaldehyde due to specific properties of MTBE and ethanol.

The combined effects of changes in driving and changes in air toxics are too small to make any

difference to the cost-benefit ranking of the alternatives. This analysis indicates that replacing MTBE with ethanol would result in a change in air quality benefits ranging from $26.8 to $30.2 million with an expected value of $28.5 million. Approximately 82 percent of these benefits would be due to reductions in toxics and approximately 18 percent to reduced fuel consumption. If a waiver was granted, allowing non-oxygenated fuel to be used throughout California, the estimated air quality benefits of switching from MTBE to this non-oxygenated RFG range from $22.6 to $28.3 million with an expected value of $25.4 million.

Costs associated with water quality are the incremental costs attributable to the specific formulation of gasoline (MTBE, ethanol, or non-oxygenated RFG) for cleanup of gasoline spills. These costs include (1) response costs at LUST sites; (2) costs to treat drinking water wells impacted by these LUST sites; (3) response costs from pipeline leaks of gasoline; and (4) the costs to monitor surface water reservoirs. The ethanol and MTBE RFG formulations were expected to increase water quality impacts of gasoline spills relative to the impacts of spills of conventional gasoline, and it has been predicted that MTBE may have a larger impact on water quality than ethanol or alkylates.

Costs associated with water quality are significant but never large enough to offset other costs of choosing an alternative to MTBE. The expected savings in water monitoring and treatment costs attributable to switching from MTBE to ethanol range from $5.3 to $578.8 million with an expected value of $122.7 million. Approximately 78 percent of these savings are attributable to response costs at LUST sites, 20 percent to drinking water wells, less than 1 percent to pipeline leaks, and less than 2 percent to monitoring of surface-water reservoirs. The expected savings in water monitoring and treatment costs attributable to switching from MTBE to non-oxygenated RFG range from $15.9 to $635.6 million with an expected value of $164.8 million.

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APPENDIX A
QUANTIFICATION OF COSTS AND BENEFITS

Markets

Reformulated gasoline in California, remainder of United States.
U.S. and world petroleum (crude oil, refined products).
U.S. and Canadian natural gas.

Representation of Markets

This section describes the explicit market models algebraically and derives the expressions used to compute consumer and producer surpluses as integrals under explicit demand and supply curves. It also explains the concepts of producer and consumer surplus used and why they are the appropriate measures of net private and social costs.

Demand

Variables	Description
D_{GX}	Demand for gasoline in region X where X can be California or the rest of the United States.
D_{RPX}	Demand for refined products in region X where X can be the United States or the rest of the world. Note that for the United States this variable represents demand for all refined products *except* gasoline, whereas for the rest of the world the corresponding variable represents all refined products *including* gasoline.
D_{NX}	Demand for natural gas in region X where X can be the United States or Canada.

Supply

Variables	Description
S_{CX}	Supply of crude oil in region X where X can be the United States or the rest of the world.
S_{NX}	Supply of natural gas in region X where X can be the United States or Canada.

Price

Variables	Description
P_{GX}	Price of gasoline (to consumer) in region X where X can be California or the rest of the United States.
P_{RPX}	Price of refined products in region X where X can be the United States or the rest of the world.
P_{Crude}	Price of crude oil.
P_N	Wellhead price of natural gas.

Driving

Variables	Description
VMT	Vehicle miles traveled.
MPG	Fuel economy in miles per gallon.

Variables	Description of Elasticities	Value or Range
σ_G	Demand for gasoline.	0.2 to 0.4
σ_{RP}	Demand for refined products.	0.08 to 0.16
σ_{VMT}	Demand for VMT.	0.1 to 0.2
σ_{MPG}	Demand for fuel economy.	0.0 to 0.3
σ_N	Demand for natural gas.	0.09 to 0.27
ε_{CX}	Supply of crude oil.	0.2
ε_N	Supply of natural gas.	0.25 to 0.75

Demand for Gasoline

$$D_G = A_G \times P_G^{-\sigma_G}$$

Gasoline demand is the product of two variables, vehicle miles traveled (VMT) and gallons consumed per mile (1/MPG). Consumers make short-run decisions about driving in response to fuel prices (carpooling, vacation trips, weekend travel, discretionary shopping), and in the long run, the fuel economy of new cars and ultimately the fleet reflects a balancing of the costs of introducing fuel-saving technologies and changes in the mix of vehicles toward smaller and more fuel-efficient models against the resulting savings in fuel consumption. VMT falls in response to higher gasoline prices, and fuel economy (expressed in miles per gallon or mpg) increases in response to higher gasoline prices, so the two elasticities of demand are opposite in sign. Therefore:

$$\sigma_G = \sigma_{VMT} - \sigma_{MPG}.$$

The analysis distinguishes between demand for gasoline in California, D_{GCal}, and demand for gasoline in the rest of the United States, D_{GXCal}. Demand for other refined products is denoted D_{RPUS} and total demand for petroleum products in the United States is $D_{GCal} + D_{GXCal} + D_{RPUS}$. The demand for refined products outside the United States is denoted as D_{RPNUS}.

In general, demand for gasoline and refined products is a function of the world oil price plus the appropriate refiners' margin, written as $P_{crude} + RM_{product, region}$. For simplicity, $RM_{product, region}$ is assumed to be fixed, equivalent to assuming constant marginal refining costs.

Effects of MTBE on Gasoline Demand in California

The increase in refining costs, including the value of lost fuel economy, increases the price of gasoline in California. The per-gallon cost of producing a replacement for MTBE is added to the refiners' margin for gasoline in California. The calculated value of the loss in fuel economy is included in the cost of producing the MTBE replacement.

The quantity of gasoline demand in California is shifted outward by the two additive factors of the net loss in volume due to removal of MTBE and the reduction in fuel economy. *MTBEShift* is defined as the sum of the effects of replacing MTBE volume and the change in fuel economy. It is calculated by multiplying the percentage loss of volume and change in fuel economy by baseline gasoline consumption in California. Thus, in the MTBE ban, the demand for gasoline in California is represented by

$$D_{GCal} \, (p_{CrudeMTBEBan} + RM_{GcalMTBEBan}) + MTBEShift$$

where $RM_{GcalMTBEBan} = RM_0 + Fuelcst$ equals the absolute increase in the cost of refining plus the value of lost fuel economy.

World Oil Market

The supply of crude oil in the United States is S_{CUS} and the supply of crude oil in the rest of the world is S_{CXUS}. Crude supply is a function of the price of crude oil, P_{crude}.

The market-clearing equilibrium condition that must be satisfied by P_{crude} is

$$D_{GCal} + D_{GXCal} + D_{RPUS} + D_{RPNUS} = S_{CUS} + S_{CXUS}.$$

The model is benchmarked to year 2000 forecasts from the Energy Information Administration's *Annual Energy Outlook 2001* and then solved with the shifts in demand and supply associated with the MTBE ban to estimate impacts of the demand on supply, demand, and prices.

Natural Gas Supply and Demand

$$D_N = A_N \times P_N^{-\sigma_N}$$
$$S_N = B_N \times P_N^{\varepsilon_N}$$

Natural gas supply is a function of the wellhead price of natural gas, P_N. The market-clearing equilibrium that must be satisfied by P_N is

$$D_{NUS} + D_{NCanada} = S_{NUS} + S_{NCanada}.$$

Data

The following table provides the data used to benchmark the oil supply and demand model, elasticity assumptions, and values for MTBE ban costs and shift factors.

2000 Data		
U.S. Natural Gas		
Demand	22.24 trillion cubic feet	
Production	18.72 trillion cubic feet	
Imports	3.51 trillion cubic feet	
Canada Natural Gas		
Demand	3.10 trillion cubic feet	
Production	6.61 trillion cubic feet	
Crude Oil Production		
United States	9.16 million barrels/day	
Rest of World	67.48 million barrels/day	
Demand for Refined Products		
California Gasoline	14,490 million gallons/year	
Rest of U.S. Gasoline	114,895 million gallons/year	
Other U.S. Refined Products	11.05 million gallons/year	
Rest of World Refined Products	56.50 million gallons/year	
World Oil Supply	76.65 million barrels/day	
U.S. Oil Consumption	19.48 million barrels/day	
Prices		
California Gasoline	1.64 dollars/gallon	
World Oil Price	27.59 dollars/barrel	
Natural Gas Wellhead Price	3.28 dollars/million British Thermal Units	
Critical Parameters	**Ethanol**	**Non-Oxygenate**
Refiner Cost (dollars/gallon)	$0.032	$0.049
Change in Fuel Economy	−0.8%	0.5%
Petroleum Volume Offset	5.8%	11.5%
Natural Gas Volume Increase	11.5%	11.5%

Sources: U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2001*; National Petroleum Council, 1999.

Estimation of Consumer Surplus Loss

Consumer Surplus in the California Gasoline Market

An MTBE ban causes the following impacts to the effective price of California gasoline:

- An additive increase in the refiners' margin equal to the change in refining cost (including the fuel economy penalty).
- An additive increase in the price of gasoline equal to the increase in the world crude oil price.

These changes alter the limits of integration used for calculating consumer surplus. The change in fuel economy alters gasoline consumption, but this analysis assumes that welfare is proportional to driving, not gasoline consumption, and does not include any welfare gain from the greater gasoline consumption required to provide the same VMT after the MTBE ban.

Consumer Surplus in Other Products

Consumer surplus in other refined product markets, including gasoline consumed in the rest of the country and all other refined products, is affected only by the change in the world crude oil price.

Cost of Producing Crude Oil

The increase in real resource cost of producing crude oil domestically is determined by the increase in the world crude oil price.

Cost of Oil Imports

The real resource cost of increased oil imports is the increase in the world oil price times the equilibrium quantity of imports after the MTBE ban. Other costs of increased oil imports are accounted for in consumer surplus losses in refined product consumption and cost increases in crude oil production attributable to higher oil prices.

Welfare Loss for the United States

The total change in consumer and producer surpluses and the cost of oil imports, including the cost to refiners, is given by the formula

$$Surplus_{Total} = \begin{array}{l} \int_{p_{Crude0} + RM_{GCal0}}^{p_{CrudeMTBEBan} + RM_{GCalMTBEBan}} D_{GCAL}(p)dp + \\[2em] \int_{p_{Crude0}}^{p_{CrudeMTBEBan}} [D_{GXCAL}(p + RM_{GXCal}) + D_{RP}(p + RM_{RP}) - S_C(p)]dp \end{array}.$$

The price of crude oil with and without the MTBE ban is obtained from the world oil market model previously described. The refiners' margin for California includes the adjustment for the cost of producing an alternative to MTBE and the penalty for lost fuel economy, so both these costs are included in the welfare calculation. The final term in the above equation, $S_C(p)$, serves, when the integration is performed, to net out transfers from domestic consumers to domestic producers so that only the increased cost of oil imports counts as a real resource cost.

In addition, petroleum demand in the United States is shifted up by the two additive factors of the net loss in volume due to removal of MTBE and the reduction in fuel economy. These two factors are not included in the values of supply or demand using the preceding formula, so the total cost of an MTBE ban equals

$$TotalCost = Surplus_{Total} + MTBEShift \times [p_{CrudeMTBEBan} - p_{Crude0}]$$

where *MTBEShift* is a quantity of gasoline equal to the sum of the quantity required to replace MTBE volume and the quantity required to replace lost fuel economy.

Figure A1 illustrates this calculation. There are three areas to be calculated. *Triangle A* is the loss in consumer surplus due to lost consumption caused by higher prices (or the gain due to lower prices in the case of natural gas). *Triangle B* is the increase in the cost of producing oil domestically due to the supply response to higher prices (or the reduction in cost due to the domestic supply response to lower gas prices). *Rectangle C* is the change in the cost of the quantity imported before the change in price.

The preceding expressions calculate this area by integrating the demand curve $D(p)$ to obtain the area to the left of the new demand curve and integrating the supply curve $S(p)$ to obtain the

Figure A1. Calculation of Consumer and Producer Surplus and Change in Cost of Imports

area to the left of the domestic supply curve. The difference between these two integrals gives the areas $A + B + C$. Integrals of the supply and demand functions in the equation are calculated as follows from the assumed elasticities and parameters. Since all demand functions have the same form, the integral that equals loss of consumer surplus plus increased cost of production can be written as

$$\int_{p_0}^{p_{MTBEBan}} D(p)dp = \int_{p_0}^{p_{MTBEBan}} A_p^{-\sigma}\, dp = \frac{A}{1-\sigma}\, [\, p_{MTBEBan}^{1-\sigma} - p_0^{1-\sigma}\,]$$

and the area that represents the area between the supply curve and the price axis (which is the transfer between domestic consumers and producers that must be netted out of the calculation) as

$$\int_{p_0}^{p_{MTBEBan}} S(p)dp = \int_{p_0}^{p_{MTBEBan}} B_p^{\varepsilon}\, dp = \frac{A}{1+\varepsilon}\, [\, p_{MTBEBan}^{1+\varepsilon} - p_0^{1+\varepsilon}\,].$$

These integrals are evaluated numerically using the equilibrium values for supply, demand, and prices in the base case (p_0 for example) and the MTBE-ban case ($p_{MTBEBan}$, for example) for either an ethanol or a non-oxygenated replacement.

APPENDIX B
COMPARISON OF CARB PHASE 2 AND
PHASE 3 REGULATIONS

Fuel Property	Units	Flat Limit		Averaging Limit		Cap Limit	
		CaRFG Phase 2	CaRFG Phase 3 -	CaRFG Phase 2	CaRFG Phase 3 -	CaRFG Phase 2	CaRFG Phase 3 -
Reid Vapor Pressure (RVP)	psi, maximum	7	7.0 or 6.9 with Evaporative PM10 -	NA	NA	7.0	6.4−7.2
Sulfur (SUL)	ppm weight, maximum	40	20	30	15	80	60 currently; 30 as of 12/31/04
Benzene (BENZ) -	volume percent, maximum	1	0.8	0.8	0.7	1.20	1.1
Aromatic HC (AROM) -	volume percent, maximum	25	25	22.0	22.0	30.0	35.0
Olefin (OLEF)	volume percent, maximum	6.0	6.0	4.0	4.0	10.0	10.0
T50 − Temperature at 50 percent distilled	degrees F, maximum	210	213	200	203	220	220
T90 − Temperature at 90 percent distilled	degrees F, maximum	300	305	290	295	330	330
Oxygen (OXY)	weight percent	1.8−2.2	1.8−2.2	NA	NA	Winter areas 1.8−3.5; 0−3.5	Winter areas 1.8−3.7; 0−3.7
MTBE (and oxygenates other than ethanol)	NA	Prohibited; as provided in § 2262.6	NA	NA	NA	NA -	Prohibited; as provided in § 2262.6

Source: California Air Resources Board.

APPENDIX C
DEVELOPMENT OF CARB AND FEDERAL RFG REGULATIONS

Date	Jurisdiction	Action
1990 and earlier	**California**	Auto/Oil study group formed (October 1989).
		Congress allows California to craft its own controls on motor vehicle fuels (in addition to national standards). See *42 USC Section 7545(c)(4)(B)*.
		CARB is authorized under state law to establish motor vehicle fuel specifications (California Health and Safety Code Sections 43013 and 43018).
		CARB adopts Phase 1 regulations in September 1990 and begins public hearings on a more comprehensive set of standards.
1990	**Federal -**	Clean Air Act Amendments of 1990, Sec 211k, require EPA to promulgate regulations for RFG including "specifications and performance standards." Also defines a "summer baseline gasoline" (defined by properties including sulfur, benzene, RVP, aromatics, distillation points, and olefins) and a "formula fuel" (unleaded with specified percent of benzene, aromatics, oxygen). Reduction in emissions is to be the greater of that from the formula fuel or 15 percent reduction in emissions from baseline vehicles and baseline fuel.
02/08/91	**Federal**	Announcement of intent to form an advisory committee for a negotiated rulemaking on RFG (56 FR 5167).
03/14/91	**Federal**	First meeting of RFG advisory committee. -
07/09/91	**Federal**	Notice of Proposed Rulemaking on RFG (56 FR 31176). Proposes simple model based on benzene, aromatics, RVP, and oxygen.
11/91	**California**	CARB adopts Phase 2 regulations at a November 1991 public hearing (effective March 1, 1996). See 13 California Code of Regulations, Sections 2250−72.
		CARB begins developing its predictive model shortly after November 1991.
1992	**California**	California Phase 1 RFG required. -
04/16/92	**Federal**	SNPRM 56 FR 13416 announces the outline of a program agreed to in the regulations negotiation. Proposes simple model and a rulemaking to develop the complex model, which will also apply to Phase 2, by March 1, 1993.
02/26/93	**Federal**	Notice of Proposed Rulemaking on complex model and Phase 2 performance standards.
02/16/94	**Federal**	Final rulemaking on RFG, including specification of complex model 40 (CFR Part 80).
06/94	**California**	Predictive model adopted by regulation at a hearing. -
03/01/96	**California**	California Phase 2 RFG production begins. -
1998	**Federal**	Phase 1 RFG: complex model required.
06/01/00	**Federal**	Phase 2 summer RFG required.

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