

RFG/MTBE

Findings & Recommendations



August 1999

Summary of Findings & Program Recommendations

OVERVIEW

The federal reformulated gasoline (RFG) program is an important air pollution control and public health protection strategy in the Northeast. Methyl tertiary butyl ether (MTBE) is an additive widely used in the blending of RFG to comply with the oxygen mandate in the Clean Air Act. MTBE emerged as the oxygenate of choice for many gasoline refiners because of its low cost and high-octane characteristics. MTBE is also added to some conventional gasoline blends as an octane enhancer, with higher levels used in premium grades.

Due to increased rates of detection in surface and groundwater, states in the Northeast and elsewhere are considering or instituting legislative and regulatory actions to reduce the use of MTBE in gasoline. Similar concerns among federal officials led to the convening of a Blue Ribbon Panel on Gasoline and Oxygenates to provide guidance to the federal government on this issue. The Panel's final report concludes, "MTBE, due to its persistence and mobility in water, is more likely to contaminate ground and surface water than other components of gasoline."¹

The challenge facing elected officials and environmental regulators is to determine the appropriate use of a chemical compound that produces substantial public health benefits while simultaneously posing an unacceptable risk to water resources. The tension between public health and environmental resource protection posed by MTBE is relatively unusual. Generally, compounds that pose substantial environmental risk are similarly detrimental to public health. In this traditional dynamic, the obvious pathway for regulatory action is to diminish the use of such compounds to the greatest extent possible. In this case, however, the solution is not as simple since gasoline is a complex mixture of dozens of toxic constituents, many of which are known human carcinogens. As MTBE is reduced or eliminated from the fuel supply, gasoline producers will add other compounds with known and unknown public health risks to make up the lost volume and octane provided by MTBE.

The most economical near-term option available to refiners supplying the Northeast RFG market may be to increase levels of aromatic compounds including benzene, toluene and xylene. These are toxic compounds that will adversely affect public health. The challenge facing the northeast states and the nation is to identify a pathway that effectively mitigates the environmental risks posed by MTBE while maintaining the public health benefits of the current RFG program. The findings and recommendations that follow present a prescription for state and federal action to effectively characterize and aggressively mitigate the environmental risks posed by MTBE while seeking to maintain the public health benefits of RFG and prevent disruption of gasoline supply and resulting price increases.

¹ *Findings and Recommendations on the Use of Oxygenates in Gasoline, The Blue Ribbon Panel on Oxygenates in Gasoline, July 27, 1999.*

STUDY APPROACH

This study was undertaken in response to a November 9, 1998 request by New Hampshire Governor Jeanne Shaheen on behalf of the New England Governor's Conference. Specifically Governor Shaheen requested that NESCAUM:

"Review the use and effectiveness of MTBE as a pollution reducing component of RFG, consider what effective alternatives may exist that are consistent with statutory options or requirements, and make recommendations regarding the best course for the [Northeast] region to pursue in order to maximize air quality benefits and minimize public health threats."

In April 1999, NESCAUM produced a series of technical papers summarizing available information on the costs and benefits of the RFG program, characterizing the environmental prevalence and fate of MTBE in the region, and identifying program options for further evaluation. These technical papers have been revised in response to public comments received and additional analysis performed over the last four months. They are appended to this Summary as attachments: (I) Health Effects of Gasoline Constituents; (II) MTBE in Ground and Surface Waters of the NESCAUM Region; (III) Air Quality, Fuel Supply and Cost Impacts of MTBE and its Alternatives; and (IV) Impact of MTBE on Treatment and Remediation of Water Resources in the Northeast.

This summary report highlights the key findings of the Technical Papers. Based on the analysis documented in the attached appendices, NESCAUM recommends a comprehensive set of federal, regional and state actions in response to concerns raised about MTBE. A more detailed discussion of the background and history of the RFG program can be found in the Draft Issues and Options papers released in April 1999 and available at www.nescaum.org.

SUMMARY of RECOMMENDATIONS

NESCAUM proposes a multi-component strategy that includes:

1. Legislative and regulatory initiatives to reduce the amount of MTBE in gasoline;
 - Congressional action to lift federal oxygen mandate in RFG
 - Clarification of USEPA and state authority to regulate fuel additives
 - Three year phase down and cap on MTBE in all gasoline
2. USEPA action to prevent air quality backsliding;
 - Regulatory revisions to prevent toxic emissions increases from MTBE phase-down
3. Regional assessment of opportunities to enhance gasoline storage tank programs;
 - Expansion to smaller tanks and above ground tanks
 - Enhanced monitoring and enforcement
4. Regional multi-media monitoring and assessment program;
 - Develop regional baseline of methodologically consistent air and water quality data
 - Track the impacts of changes in gasoline formulation
5. Scientific assessment of MTBE alternatives;
 - Develop streamlined screening process and employ prior to wide-scale use
 - Complete testing of basic gasoline constituents as required under the CAA
6. Analysis of the fuel supply and price impacts of diminishing MTBE use; and
 - Refinery modeling of options that maintain RFG air quality benefits in the Northeast.
7. Public education and outreach to diminish the incidence of small commercial and residential gasoline spills.
 - Expand Alliance for Proper Gasoline Handling

Because RFG and the oxygenated fuels program are federal initiatives, NESCAUM believes that a federal solution is warranted and optimal. Absent an appropriate federal response, a regional solution will be pursued in the Northeast.

SUMMARY of KEY FINDINGS

Health Effects of Gasoline Constituents

- Conventional gasoline is a complex mixture containing highly toxic compounds, many of which are known or suspected human carcinogens. Exposure to these toxins in the air and water present potential health risks to the general public.
- The RFG program is a proven and cost-effective air pollution reduction strategy. The northeast states must maintain and improve upon existing clean burning gasoline programs in order to attain and maintain the National Ambient Air Quality Standards (NAAQS) for ozone and carbon monoxide. RFG also helps reduce public exposure to a host of hazardous air pollutants such as benzene, 1,3-butadiene, acetaldehyde and formaldehyde that currently exceed health protective thresholds in the Northeast.
- The aggregate public health benefits RFG provides by reducing air pollution substantially outweigh potential adverse public health impacts from exposure to increased levels of MTBE in the air and water. Tens of millions of northeast residents benefit from reduced exposure to mobile source air toxics, whereas exposures to MTBE at levels above health thresholds are rare.
- MTBE, at levels typically found in the region's air and water, does not pose a health threat to the general population. However, the presence of MTBE in excess of drinking water standards (about 1 percent of sampled wells in the Northeast), in combination with exposure to MTBE in outdoor air, may in some cases be sufficient to exceed health protective thresholds.
- Gasoline refiners that supply the Northeast have overcomplied with RFG toxic performance standards by more than 75 percent, in part due to the presence of MTBE. This substantial margin of overcompliance may be lost if MTBE is reduced or eliminated from RFG. In addition, toxic air emissions from conventional gasoline sold in the Northeast have declined 13 percent since 1990, and those emission benefits may also be diminished or lost if MTBE is phased out of RFG.
- Existing public health testing requirements for gasoline components and additives are inadequate. A streamlined risk screening process, which accounts for environmental fate, transport and toxicity must be performed prior to the widespread introduction of new additives or significantly increasing the level of current gasoline additives. Absent such analyses, it will be difficult to confidently protect public health and environmental quality from future changes in the fuel supply.

Water Quality Impacts

- MTBE poses unique risks to ground and surface water compared to other components of gasoline due to its mobility and resistance to biodegradation.
- The "turpentine-like" taste and odor of MTBE can make drinking water unacceptable to consumers.
- MTBE is now one of the most commonly detected VOCs in Northeast drinking water supplies. Wells with MTBE contamination often do not contain detectable levels of other toxic gasoline compounds. For example, in a USGS study of the Northeast, benzene was found in only 12 percent of wells with detectable levels of MTBE.

- The vast majority of MTBE detections (98%) are at levels well below the most stringent state health thresholds. Atmospheric deposition, storm water runoff and small-scale surface spills are the probable sources of this low-level contamination. None of these mechanisms are likely to cause long-term contamination of groundwater at concentrations approaching or exceeding drinking water standards.
- Leaking underground storage tanks represent the primary threat to drinking water because the volume of gasoline released can be significant and historically these leaks could go undetected for long periods of time.
- MTBE contamination adds \$34 million to the cost of cleaning up gasoline spills in the Northeast. This expense accounts for one-third of the total cost of remediating gasoline-contaminated groundwater in the Northeast. Placed in context with annual expenditures on gasoline, MTBE cleanup costs are equal to raising the price of gasoline sold in the Northeast by 0.25 cents per gallon over the course of a year.
- Over the last decade, the northeast states have made substantial progress removing existing underground storage tanks and replacing them with upgraded tanks with release detection equipment and procedures. These efforts and further improvements have and will continue to greatly diminish the potential for contamination of water resources by gasoline.
- While gasoline releases will still occur from refueling and accidental spills, the risk to water resources from small leaks and spills should diminish substantially with lower levels of MTBE in gasoline since a linear relationship exists between the amount of MTBE in the gasoline and the concentration in contaminated water.

Fuel Supply and Costs

- A variety of petroleum and non-petroleum based compounds (aromatics, alkylates, toluene, ethanol, etc.) are available to replace MTBE. Each of these compounds present economic and environmental advantages and disadvantages compared to MTBE. The relative increase in these compounds will depend on the balance between environmental fate, persistence, public health impacts and economic considerations adopted through federal and state action.
- Changes to the RFG program are likely to have substantial impacts on the environmental characteristics of the conventional gasoline pool. Conventional gasoline makes up roughly one quarter of the fuel sold in the NESCAUM region and two thirds of the fuel sold nationally. Existing federal statute and regulations are inadequate to prevent a degradation of conventional fuel quality resulting from changes in the RFG program.
- Changes to gasoline formulation should be implemented on a regional or national basis, with adequate lead-time to diminish the possibility that such changes result in supply instability and unacceptable increases in gasoline prices. A one cent per gallon change in gasoline price is equivalent to \$120 million in the region's economy over the course of one year.

AIR QUALITY IMPACTS OF RFG AND MTBE

Motor vehicles are the largest aggregate source of air pollution in the Northeast. As a sector, gasoline powered vehicles emit about one-third of smog-forming volatile organic compounds (VOCs) and oxides of nitrogen (NO_x) in the region. Vehicles are also the primary source of carbon monoxide. The results of the U.S. Environmental Protection Agency's (USEPA's) recent Cumulative Exposure Project (CEP) suggest that about half of the public health risk from airborne hazardous air pollutants (HAPs) is associated with exposure to automobile emissions.² Figure 1 compares measured annual average ambient concentrations of several motor vehicle-related air HAPs in the Northeast to established health protective guidelines.³ Monitoring data represent the highest and lowest annual average measurements of ambient concentrations for each compound. The health-protective standards represent levels determined to be protective against carcinogenic effects (as published by Caldwell *et al.* for the CEP analysis).⁴ These data show that even the lowest measured outdoor concentration of acetaldehyde, benzene, 1,3-butadiene and formaldehyde in the Northeast region-- the pollutants regulated under the RFG program -- exceed the cancer standards established for these compounds. Whereas, the highest measured levels of MTBE in the air are about one-half the health standard.

Figure 1

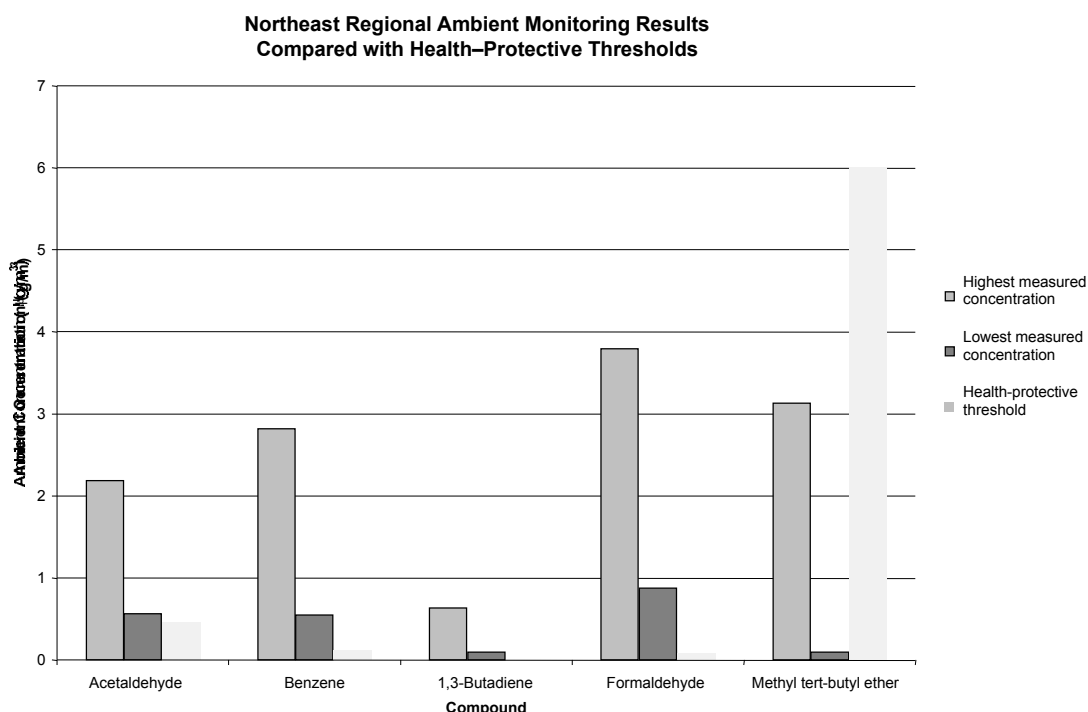


Table 1 shows the source sectors responsible for regional average emissions of acetaldehyde, benzene, 1,3-butadiene, and formaldehyde in the Northeast. This table was developed using the northeast states'

² *Public Health Implications of 1990 Air Toxics Concentrations across the United States*, Tracey J. Woodruff, et al, 1998.

³ Quality assured ambient monitoring results provided to NESCAUM by respective Northeast States Air Quality Agencies. These data are collected in accordance with USEPA ambient monitoring requirements.

⁴ Caldwell, Jane C., Woodruff, T.J., Morello-Frosche, R., Axelrad, D.A. Application of Health Information to Hazardous Air Pollutants Modeled in EPA's Cumulative Exposure Project. *Toxicology and Industrial Health*, vol. 14, No. 3, pp. 429-454, 1998.

emissions inventory compiled for the 1990 CEP analysis⁵. Approximately two-thirds of these HAPs are emitted by motor vehicles.

Table 1
Toxic Air Pollutants of Concern in the Northeast Region

	Mobile	Area	Point	Total
Acetaldehyde	62%	35%	3%	100%
Benzene	71%	28%	2%	100%
1,3-butadiene*	65%	25%	<1%	91%
Formaldehyde	68%	30%	2%	100%

** Additional 9% of emissions attributed to secondary formation*

Cleaner-burning gasoline is an effective strategy for reducing emissions that contribute to smog, carbon monoxide, fine particulate matter, haze, acid deposition, and toxic problems in the region. Two attributes make cleaner-burning gasoline a particularly important and effective approach to air pollution control. First, the program benefits accrue immediately upon introduction of the fuel; as opposed to new vehicle standards where the full benefits are not achieved until significant fleet turnover has occurred (about 12 years for a 90% turnover). Second, the benefits – while different in magnitude - apply to all vehicles, regardless of age and technology.

The RFG program was designed to reduce ambient levels of ozone, a powerful respiratory irritant that adversely affects the health and well being of large segments of the population including children, the elderly and individuals engaged in outdoor activities. While ozone smog remains a persistent summertime problem in the Northeast, existing data suggest that the RFG program has contributed to reduced levels of smog where it has been used.⁶ The ozone benefits of this program are expected to increase with the introduction of Phase II RFG which requires additional reductions in VOCs and especially NOx.

MTBE is also widely used in oxygenated gasoline (oxyfuel). Oxyfuel, which requires a minimum of 2.7 percent oxygen by weight, has been an effective wintertime carbon monoxide (CO) control strategy in the New York City metropolitan area and elsewhere. The presence of oxygenate in the gasoline serves to reduce CO emissions by promoting more complete fuel combustion. Due to the benefits of new motor vehicle standards and the use of cleaner burning oxyfuel, substantial progress has been made in achieving the NAAQS for carbon monoxide. In August 1999, the state of Connecticut announced the decision to opt its portion of the New York City metropolitan area out of the oxygenated fuel program. New Jersey and New York are planning to request redesignation as carbon monoxide attainment areas. They will likely eliminate the use of oxyfuel in the wintertime once the area is formally designated as attaining the NAAQS for carbon monoxide. RFG also provides carbon monoxide benefits and is seen as a long-term strategy for maintaining compliance with the CO NAAQS. Should the RFG oxygen mandate be lifted, USEPA should ensure that carbon monoxide emissions from vehicles operating on RFG do not increase.

⁵ Unpublished data provided by USEPA, Office of Policy. Final emissions inventory used for Cumulative Exposure Project, Assessment of Population Exposure Nationwide computer dispersion modeling, provided 1998.

⁶ *Cleaner-Burning Gasoline: An Assessment of its Impact on Ozone Air Quality in California*, California Air Resources Board, January 1998 (December 1998 Supplement) and *Ozone-Forming Potential of Reformulated Gasoline*, National Research Council, May 1999.

Air quality monitoring data demonstrate that Phase 1 of the RFG program has significantly contributed to reduced ambient levels of HAPs including benzene, a known human carcinogen.⁷ As shown in Table 2, gasoline refiners have significantly overcomplied with the minimum statutory toxic reduction requirements of Phase 1 of the RFG program. Analyses conducted by the northeast states and others suggest that benzene is a primary source of public health risk from exposure to vehicular emissions. The RFG program imposes a 1 percent by volume cap on benzene; most refiners are using considerably less than the allowable level (on average about 0.6 %). When combusted in motor vehicles, aromatics also result in benzene emissions. Ambient monitoring data show that outdoor levels of this carcinogen have declined dramatically where RFG is used. On average, benzene concentrations have decreased by 43 percent in areas where RFG is used. Ambient levels of 1,3-butadiene and acetaldehyde have also decreased in these areas. The use of RFG with MTBE has, however, resulted in increased airborne emissions of MTBE and formaldehyde. Table 2 summarizes the emission benefits of federal RFG compared to 1990 conventional gasoline.

Table 2
Emissions Reductions from Federal RFG in the Northeast States

Pollutants	Phase I RFG (1995 – 1999)		Phase II RFG (2000+)
	<i>Performance Standards</i>	<i>Actual Emission Reductions (1998 average)</i>	<i>Performance Standards</i>
VOCs	17.1%	21%	27.4%
NO_x	1.5%	5%	6.8%
Toxics (mass emissions)	16.5%	35%	21.5%

FUEL QUALITY

If MTBE use is phased down or banned without additional regulatory steps to secure current air toxics emissions performance of RFG, it is likely that mobile source air toxic emissions will increase. Refineries that supply the Northeast have overcomplied with Phase II RFG toxic performance standards by more than 75 percent, due in part to the presence of MTBE. This substantial margin of overcompliance may be lost if MTBE is reduced or eliminated from RFG. Analyses conducted by NESCAUM suggest that toxic air emissions from conventional gasoline sold in the Northeast have declined by 13 percent since 1990. Additional analysis is needed to determine whether changes to RFG formulations resulting from a phase-down of MTBE will diminish these benefits.

The use of oxygenates, such as MTBE and ethanol, contributes to reductions in air toxic emissions from motor vehicles through dilution and replacement of toxic gasoline constituents that are high in octane. Several sources of data strongly suggest that an increase in MTBE content results in a corresponding decrease in levels of aromatics, a major source of benzene emissions in motor vehicles. For example, the state of Maine recently implemented its own fuel program that does not require the use of oxygenates. The fuel properties reported by Maine's gasoline suppliers and distributors show a decrease

⁷ National Air Quality Emission Trends Report, USEPA, 1995; Analysis of Photochemical Assessment Monitoring Station Data to Evaluate a Reformulated Gasoline Effect, Sonoma Technologies Inc, 1998

in MTBE use by 50 percent and a corresponding increase in aromatics of 70 percent over the levels of aromatics present in RFG sold in Maine in 1997. In addition, EPA conducted a statistical analysis of 1998 RFG fuel properties and found that for regular grade gasoline, when MTBE decreases, aromatics, benzene and olefins tend to increase.

Available refinery modeling predicts that over time ethanol is the most likely gasoline additive to replace MTBE, even if the oxygenate mandate is removed. However, several significant air quality issues need to be addressed before northeast states pursue policies that result in increased use of ethanol. Combustion of ethanol-blend gasoline results in substantial (50 to 70 percent) increases of acetaldehyde emissions and ambient levels of acetaldehyde are presently far in excess of health-based risk standards in the Northeast. Refineries are likely to use ethanol at 10 percent by volume in conventional gasoline to take advantage of the statutory one pound volatility waiver, which would lead to a substantial increase in VOC emissions. For this reason, NESCAUM recommends elimination of this volatility waiver for ethanol. Unless all gasoline sold in the region contains ethanol, the blending or commingling of ethanol with non-ethanol gasoline blends in vehicle gas tanks will result in a significant increase in VOC emissions due to increased fuel volatility. On the positive side, ethanol, and especially locally produced biomass ethanol, has the potential for reducing CO₂ emissions, eliminating the need for waste disposal, and retaining \$120 million per year in the Northeast economy.

Aromatics and alkylates are the two most likely non-oxygenate alternatives to MTBE. Aromatics is a term for a group of gasoline constituents that includes benzene, toluene and xylene. These compounds are relatively high in octane. The use of aromatics to replace MTBE will substantially increase toxic emissions from motor vehicles operated on RFG and conventional gasoline. Alkylate provides octane without apparent increases in toxic emissions, and may not pose a risk to water resources. However, due to these attractive features, alkylate is already in short supply. The health effects of alkylate are not well understood. A rigorous evaluation of the potency, combustion by-products and environmental fate and transport of alkylate and other likely replacements for MTBE should be conducted prior to any substantial increase in their use.

The desire to achieve substantial reductions in MTBE, coupled with potential legal constraints and concerns about the near-term viability of alternatives to MTBE, has led some states to opt out of the RFG program. To date, the states that have opted out of the RFG program have done so without economic hardship, but the gasoline sold in these states does not provide the air quality benefits of the RFG program. NESCAUM strongly recommends additional refinery modeling to estimate the costs associated with a phase down of MTBE while preserving current levels of air toxic reductions in the RFG and conventional gasoline pools.

It is technically possible to produce a gallon of gasoline with no MTBE that achieves benefits equivalent to and even greater than the present performance of RFG in the Northeast. It is likely, however, that an immediate ban on MTBE cannot be accomplished without substantial increases in gasoline prices, supply shortages, and a substantial increase in air toxic emissions. Hence, the decision to reduce MTBE use in the northeast states must be guided by practical considerations such as the environmental performance of MTBE replacements, alternative product availability, gasoline cost and price stability, and the lead-time required for such a transition. These issues are considered in detail in Attachment III.

FUEL SUPPLY and COST

The gasoline distribution network in the Northeast is regional in nature; program decisions in one jurisdiction have consequences in neighboring states. Nearly 75 percent of the 12 billion gallons of gasoline sold in the Northeast annually is RFG. MTBE is widely used in the Northeast market because it is relatively inexpensive, provides a good source of octane, has low volatility characteristics, and can be blended at the refinery and shipped to the region through gasoline pipelines. Over one billion gallons of MTBE are consumed in the Northeast annually. As a region, the Northeast gets about 40 percent of its gasoline from East Coast refineries, 40 percent from Gulf Coast refineries and the remaining 20 percent from foreign suppliers.

Ethanol, the primary alternative oxygenate, is commonly used in gasoline sold in the Midwest, given the proximity to production facilities and the preferential tax schemes in place in these states. NESCAUM estimates that approximately 800 million gallons per year (gpy) of ethanol would be needed in the region to replace all of the MTBE currently used. The viability of ethanol as an alternative oxygenate for the Northeast market may hinge on the resolution of considerable supply, distribution, cost and performance issues. Production capacity does not currently exist in the U.S. to meet near-term demand if both California and the Northeast move toward broad substitution of ethanol for MTBE.

The fact that ethanol is not currently produced in significant quantities in the Northeast and cannot be shipped to the region through gasoline pipelines represent important logistical barriers. Under existing conditions, ethanol would have to be shipped by barge, rail or tanker truck from production facilities in the Midwest to the Northeast and blended at bulk terminal facilities in the region. The transport of huge quantities of ethanol will, in and of itself, result in increased mobile source emissions in the region.

Developing new ethanol production capability in the Northeast could help overcome these supply and distribution hurdles. A 1994 study conducted by the Conference of Northeast Governors (CONEG) concluded that the region could support a biofuel-based ethanol production industry comparable to that of the existing corn-based industry.⁸ The CONEG study indicates that the quantity of biomass material currently discarded in the NESCAUM states and potentially available from herbaceous and short rotation woody crops could produce more than 1.8 billion barrels of ethanol per year. The CONEG study concluded that waste paper, paper sludge and cheese whey were the best current feedstock candidates for ethanol production in the Northeast.

In the longer-term, forestry wood waste could support significant ethanol production in the Northeast. Potential ethanol production in the Northeast is estimated by CONEG to be as high as 900 million gpy. This amount is equivalent to approximately two-thirds of the existing corn-based industry and slightly in excess of the amount needed to replace all of the MTBE currently used in the NESCAUM region market. However, it must be noted that there are currently no commercial ethanol biomass production facilities operating in the Northeast. While promising commercial scale facilities are in the early construction/planning stages respectively in Louisiana and California, it would take several years and considerable investment before the northeast states could produce enough bio-mass ethanol to overcome the transportation barriers noted above.

Biomass-derived ethanol presents a wide range of potential environmental and economic benefits for the northeast states. A study conducted by Argonne National Laboratory's Center for Transportation

⁸ *The Potential for Producing Ethanol from Biomass in the Northeast, Conference of Northeast Governors, 1994*

Research concludes that the net fuel-cycle GHG reductions of ethanol produced from cellulosic feed stocks range from 80 to 130 percent, relative to gasoline.⁹ Moreover, the conversion of waste streams that presently must be land filled or incinerated into a valuable commodity presents a host of significant economic and environmental benefits. The benefits of producing ethanol in the Northeast from agricultural and wood wastes are far reaching and largely beyond the considerations of air quality that underlie the Clean Air Act and RFG program. As such, appropriate policies to promote the substantial environmental and economic benefits of biomass ethanol are substantially outside the scope of the RFG program and the recommendations contained in this study.

The cost of producing RFG with reduced amounts of MTBE may vary widely. The USDOE has estimated cost changes, relative to Phase II RFG, for alternative fuel formulations ranging from a decrease of 1.5 cents if the oxygen mandate were lifted and MTBE remained in use to an increase of 10 cents per gallon for RFG with an immediate ban on MTBE.¹⁰ Moreover, these cost estimates seek merely to reflect the costs of producing a fuel that complies with the minimum statutory requirements of the RFG program and hence allow for a 40 percent increase in air toxic emissions over present RFG performance in the Northeast. The macro economic impact of relatively small changes in gasoline prices is substantial. For the twelve billion gallons of RFG sold in the Northeast annually, a change of one cent per gallon is equivalent to \$120 million. Since gasoline refining is limited in the Northeast, an increase in gasoline price will result in an outflow of resources from the regional economy.

The costs of gasoline formulation changes are highly time-sensitive. In their assessment of MTBE alternatives, the California Energy Commission concluded, "If the use of MTBE were discontinued immediately, the consequences would be dire for consumers and catastrophic for the California economy."¹¹ Analyses by California and the USDOE suggest that a minimum of three years will be needed to cost-effectively replace MTBE in reformulated gasoline.

STATE ACTIONS TO REDUCE MTBE USE

Several RFG states have already taken action to address concerns over growing MTBE contamination of their water resources. The following is a brief summary of the actions taken in Maine, New Hampshire, Connecticut and California.

State of Maine

On October 13, 1998, Governor King sent a letter to USEPA indicating Maine's decision to opt out of the federal RFG program. This decision was predicated on the findings of a state Bureau of Health study that the higher levels of MTBE in RFG were statistically linked to the risk of groundwater contamination. The report concluded that the current levels and persistence of MTBE in groundwater did not constitute an immediate public health crisis, but raised concerns that continuation of the federal RFG program would result in an exacerbation of the problem. Believing that the state lacked the authority to remain in the RFG program and adequately regulate MTBE levels in fuel, the decision was made to opt out of the RFG program altogether.

⁹ GHG reductions greater than 10% are theoretically possible because co-generation at the cellulosic ethanol conversion plant could displace fossil fuel-generated electricity.

¹⁰ *Estimating Refining Impacts of revised Requirements for Gasoline: Summary Findings*, G.R. Hadder, Oak Ridge National Laboratory, 1999.

¹¹ *Supply and Cost of Alternatives to MTBE in Gasoline*, California Energy Commission Staff Report, 1998.

The RFG program opt out was approved by USEPA as of February 1, 1999 with the following conditions: (1) Maine must identify alternative control measure(s) to provide equivalent VOC reductions to the RFG program; (2) a schedule for implementing the replacement measure(s); and (3) Maine provide an explanation of the impact to the State Implementation Plan for ozone.

As a replacement measure, Maine has adopted a low volatility conventional gasoline initiative. No gasoline delivered in the former RFG counties (York, Cumberland, Sagadahoc, Androscoggin, Kennebec, Knox and Lincoln) shall have a Reid Vapor Pressure (RVP) of greater than 7.8 pounds per square inch (psi) for the period May 1 to September 15, 1999. For the period May 1 to September 15, 2000 and subsequent years, the RVP of fuels in these counties shall not exceed 7.2 psi.

Preliminary fuel quality data suggest that the amount of MTBE in gasoline has been reduced by more than 50 percent as a consequence of this initiative. Consistent with Maine's action to substantially reduce MTBE, public concern over MTBE contamination has dissipated considerably. Based on Maine's desire to maximize the potential air quality and public health benefits of cleaner burning gasoline, the state has indicated an interest in future participation in the federal RFG program should a national or regional solution emerge to adequately reduce MTBE use.

New Hampshire

In June 1999, the New Hampshire legislature adopted an *Act relative to the prevention of MTBE contamination of drinking water and groundwater*. Citing concerns about MTBE contamination of drinking water, the uncertain health and environmental impacts of alternative clean fuel formulations, and current lack of state authority to regulate the MTBE content of RFG, the legislature instructed the Department of Environmental Services (DES) to seek a waiver to opt out of the RFG program until January 1, 2002. Consequently, the state will revert back to conventional gasoline during this interim.

The legislation also requires: continued monitoring of public and private drinking water supplies; a study of MTBE alternatives; and the adoption of primary and secondary drinking water standards for this additive. The Act further authorizes the Commissioner of DES to require lower MTBE concentrations in gasoline if readily available and reasonably priced substitute gasoline supplies exist and are approved for use in New Hampshire by the USEPA. Like Maine, New Hampshire has expressed a strong desire to rejoin the federal RFG program or a regional cleaner burning gasoline strategy should a national or regional solution emerge to adequately reduce MTBE use.

Connecticut

The Connecticut legislature recently passed a law requiring the Commissioner of Environmental Protection to report back to the General Assembly by February 1, 2000 with recommendations on "whether the continued use of MTBE is appropriate" (Senate Bill Number 630, "An Act Concerning the Use of MTBE as a Gasoline Additive," June 23, 1999). The legislation requires an investigation into four specific areas: (1) whether MTBE use should be continued and if not, an explanation of the waiver process, (2) the impact of MTBE on the state's water supply, (3) the status of other relevant state actions, and (4) recommendations on alternative or supplemental air pollution reduction programs, such as alternative vehicle incentives, mass transit and employee commute programs.

California

Citing a significant environmental threat to groundwater and drinking water, on March 1999, Governor Gray Davis directed a phase-out of MTBE use in California to be completed no later than December 31, 2002. California asked USEPA for an immediate waiver from the Clean Air Act's oxygen mandate and committed to maintaining the air quality emission standards of the RFG program. The governor also mandated a pump labeling program to inform consumers about gasoline containing MTBE. The Air Resources Board and Water Resources Control Board were directed to conduct an analysis of the environmental fate of ethanol in air and water. The Office of Environmental Health Hazard Assessment will prepare an analysis of the health risks of ethanol in gasoline and the products of incomplete combustion.

WATER QUALITY IMPACTS OF MTBE

Gasoline contamination has posed a threat to water resources since it was first introduced as a transportation fuel a century ago. Gasoline-related pollutants such as benzene, toluene, ethyl benzene, and xylenes (jointly referred to as the BTEX compounds) have long been monitored and regulated in drinking water. While it has been used as a gasoline additive for only about twenty years, MTBE is now one of the most frequently detected VOCs in Northeast drinking water supplies.

MTBE and other gasoline constituents can enter surface and ground water from leaking tanks, accidental spills, direct atmospheric deposition, and stormwater runoff. The presence of MTBE increases the threat of water contamination since this additive is highly soluble and therefore travels faster and further in soil and groundwater than other fuel constituents. Because MTBE is relatively resistant to biodegradation compared to other gasoline constituents, it persists longer in the soil and groundwater. These same characteristics also enable low level MTBE water contamination through non-point sources, which could include airborne deposition in rainfall. Boats and other gasoline-powered watercraft, particularly those powered by 2-stroke engines, are a major source of MTBE in surface water.

MTBE contamination of drinking water occurred prior to the introduction of federal RFG and oxygenated gasoline and this additive continues to be found in some drinking water in non-RFG areas. However, the incidence of MTBE-related water contamination appears to have increased substantially where RFG and oxygenated gasoline are used. MTBE has been found at low levels in about 15 percent of the drinking water tested in the Northeast. However, the vast majority of samples with detectable levels of MTBE contain less than 2 parts per billion (ppb) of this additive. Public health impacts, as well as taste and odor problems, are a concern where MTBE is present in drinking water at levels above 20 to 70 ppb. The results from a group of studies (summarized in Table 3) show that between 0.5 and 1.5 percent of water supplies tested in the Northeast contained MTBE at concentrations above the 35 ppb public health drinking water standard used in Maine (the most restrictive standard in the region).

Table 3
MTBE Concentrations in Northeast Water Supplies

Concentration Range (µg/L)	Maine Private Wells N = 946 (95% CI)	Maine Public Water Supplies N = 793 (95% CI)	USGS Studies N = 376 (95% CI)
< 0.2	85.0%	85.1%	82.2%
0.2 – 5	12.0% (10-14%)	13.6% (11-16%)	16.2% (13-20%)
5 – 35	1.9% (1.1-2.3%)	1.3% (0.6-2.3%)	1.0% (0.3-2.7%)
> 35	1.1% (0.5-1.9%)	0.0% (0.0-0.5%)	0.5% (0.06-1.9%)

Source: Presence of MTBE and other Gasoline Compounds in Maine's Drinking Water Supply: A Preliminary Report, 1998
N = Number of samples. 95% CI = 95 percent confidence interval. The USGS studies included parts of CT, MA, NJ, NH, NY, PA, and VT. Note that the smaller number of observations at higher MTBE concentrations (>5 µg/L) makes conclusions about differences between the Maine and USGS results less meaningful, as reflected by the considerable overlap in the 95% confidence intervals.

The threat of exposure to MTBE from contaminated private wells is greater because these systems are not routinely monitored as is the case with public drinking water supplies. MTBE concentrations above 35 ppb are typically associated with identifiable sources such as storage system releases or major accidental spills. However, an analysis conducted by the State of Maine suggests that relatively small spills of a few gallons can contaminate wells to levels near or above health guidelines.¹²

Table 4 shows that compared to MTBE, the BTEX compounds (with the possible exception of toluene) were infrequently detected and were typically well below health-based standards. Toluene may have been detected relatively more frequently at low levels, but more than 80% of toluene detections occurred in reprocessed samples that did not receive confirmatory sampling by trained field staff. In one study conducted by the United States Geological Survey (USGS) in the Northeast, MTBE was the most frequently detected compound of the twenty-five chemicals sampled.¹³ The fact that wells with MTBE often do not contain detectable levels of BTEX compounds points to the unique threat to water resources posed by this additive. Benzene, for example, was detected in only 12 percent of the wells where MTBE was found. The vast majority of MTBE detections in our region (98%) are at levels well below the most stringent state health thresholds. Atmospheric deposition by rainfall is one possible source of the very low MTBE concentrations seen in the majority of detections, but this source is extremely unlikely to result in contamination at levels approaching or exceeding drinking water standards.

¹² *The Presence of MTBE and Other Gasoline Compounds in Maine's Drinking Water: A Preliminary Report, Maine Dept. of Human Services, Maine Dept. of Environmental Protection, Maine Dept. of Conservation, 1998*

¹³ *Volatile Organic Compounds in Groundwater in the Connecticut, Housatonic, and Thames River Basins, S.J. Grady 1993-95: USGS Fact Sheet 029-97.*

Table 4
Detection Frequency of Gasoline Compounds in Public and Private Drinking Water in Maine

Pollutant	Private Wells	Public Water Supplies
Xylene	0.1%	1.6%
Toluene	2.1%	13.1% ¹⁴
Ethylbenzene	0.1%	0.9%
Benzene	0.5%	2.0%
MTBE	15.8%	16.0%

Source: Presence of MTBE and other Gasoline Compounds in Maine's Drinking Water Supply – A Preliminary Report, 1998

For 885 public drinking water supplies tested in New Hampshire from 1995 to 1998, 6.2 percent had detectable levels of MTBE. The concentrations were typically below 5 ppb. No community or non-transient water supplies had MTBE levels above 20 ppb. Three transient supplies had concentrations greater than 20 ppb. A transient supply is one that is used intermittently or seasonally such as at a campground.

For surface waters, gasoline contamination tends to be closely related to the use of motorized watercraft. Studies have found that MTBE and BTEX occur simultaneously at relatively low levels in lakes where gasoline-powered watercraft are used. These levels tend to increase in the summer when watercraft usage is high and decrease or disappear in the winter when usage is low. MTBE volatilizes (evaporates) from surface waters, but at a rate slower than the BTEX compounds. Air deposition and stormwater runoff may also impact surface waters. A USGS study of seven streams in New Jersey detected MTBE in eighty-seven of the one hundred and twelve samples taken. However, the median concentration was 0.42 ppb and the maximum concentration 4.8 ppb.¹⁵

Releases from storage tank systems represent the primary threat to drinking water from gasoline-contamination because the volume of gasoline released can be significant and historically could go undetected for long periods of time. To address this threat, federal and state governments embarked on a major initiative to upgrade the underground storage tank (UST) infrastructure. Most underground tanks now employ double-wall construction and incorporate monitoring systems to detect and report leaks. This program should significantly reduce the incidence of groundwater contamination from gasoline and MTBE. While many of the northeast states have UST compliance rates over 95 percent, nationally approximately 20 percent of UST regulated storage tanks have not been upgraded even though the compliance deadline has passed.

The dynamic and ongoing improvements state UST programs must be considered in determining the degree of MTBE reduction that is necessary to protect groundwater resources. However, even when fully implemented, UST program improvements alone are unlikely to provide sufficient protection against MTBE contamination at current levels of use in RFG. A large population of gasoline storage

¹⁴ Toluene may have been detected relatively more frequently at low levels, but more than 80% of toluene detections occurred in reprocessed samples that did not receive confirmatory sampling by trained field staff (see Water Quality White Paper for more detailed explanation of the uncertainty associated with this value).

¹⁵ *Occurrence of Seasonal Variability of Volatile Organic compounds in Seven New Jersey Streams*, U.S. Geological Society Survey Water resources Investigations Report, 98-4074, 1998.

tanks are not regulated under UST programs and tank failures will continue to occur, albeit at a significantly lower rate than in the past. In addition, gasoline releases can still occur from refueling and other activities associated with storage systems, even with state-of-the-art tanks. Further, accidental spills ranging from tanker truck turnovers to lawnmower overfills will remain a source of gasoline contamination of water and soil. If MTBE in RFG is substantially reduced, gasoline will pose less of a threat to water resources than at present or in the past. In particular, the risk to water resources from small leaks and spills should diminish substantially with lower levels of MTBE in gasoline since a nearly linear relationship exists between the amount of MTBE in the gasoline and the concentration in contaminated water.

IMPACT OF MTBE ON REMEDIATING GASOLINE SPILLS

Where pollutants are found in drinking water at concentrations above health-based standards, states must either treat the supply or provide an alternative source. Due to its toxic potency, benzene has historically been the water pollutant of primary concern at gasoline-contaminated groundwater sites. To put this in perspective, in Connecticut, the remediation standard for benzene is 1 ppb, 1000 ppb for toluene, and 100 ppb for MTBE. Because it is often found in groundwater without the BTEX compounds, has a low taste and odor threshold, and is persistent in groundwater, MTBE may replace benzene as the contaminant most often requiring remediation of drinking water supplies in some RFG areas.

NESCAUM conducted a survey of the northeast states in an effort to quantify the incremental increase in drinking water cleanup costs due to the presence of MTBE in gasoline. Additional information was taken from a national survey on MTBE impacts conducted by the University of Massachusetts (UMass) and USEPA which found marked differences in drinking water clean-up costs in areas with and without RFG.¹⁶ The NESCAUM survey found that in 1997, the northeast states and responsible private parties spent about \$172 million to remediate gasoline spills. Of this total \$115 million was spent in RFG areas and \$57 million in non-RFG areas. Due to its particular chemical properties and low taste and odor threshold, MTBE increases the overall cost of treating gasoline-contaminated water supplies. In RFG areas, about \$34 million or 30 percent of the total clean-up costs were related to the presence of MTBE. By contrast, the survey found that only about 6 percent of the clean-up costs in non-RFG areas were related to the presence of MTBE.

To put these costs in context, a one-cent per gallon increase in the price of the 12 billion gallons of gasoline sold each year in the Northeast results in consumer costs of \$120 million per year. Consequently, the differential remediation costs associated with the presence of MTBE in the Northeast are equivalent to a 0.25 cent per gallon increase in the price of gasoline. It should be noted that these expenditures reflect clean up costs prior to full compliance with UST regulations. Total gasoline remediation costs, including the amount attributable to MTBE, may decline commensurate with the reduction of leaking tanks.

¹⁶ Study Reports *LUST Programs are Feeling Effects of MTBE Releases, Soil and Groundwater Clean up*, August/September 1998, Robert Hitzig, Paul Kostecki, and Denise Leonard.

HEALTH EFFECTS OF GASOLINE CONSTITUENTS

For the population as a whole, the public health benefits RFG provides by reducing air pollution substantially outweigh adverse public health impacts from exposure to increased levels of MTBE in the air and water. Exposure to ambient levels of mobile source-related air toxics above health-based standards are widespread in the Northeast. At this time, MTBE contributes to substantial reductions in these air toxics through the RFG program. Conversely, ambient air and water quality monitoring in the Northeast indicate that incidents of exposure to MTBE above health thresholds are rare.

Alternative strategies for maintaining the air quality benefits of cleaner-burning gasoline while limiting the threat to water supplies will inevitably introduce different public health benefits and adverse impacts when compared against the status quo of RFG with MTBE. When assessing the likely health impacts of alternative formulations, two basic factors must be considered: the level of exposure and the potency of the toxins to which the public is exposed. Given the ubiquitous presence of motor vehicles, public exposure to all gasoline-related pollutants in the air is high. Compared to some other gasoline components, MTBE presents a higher potential for high exposure through groundwater due to its mobility and resistance to biodegradation. MTBE is significantly less potent than many other components in gasoline. The immediately available replacements for MTBE in the Northeast are aromatic hydrocarbons. The potency of these compounds is substantially greater than MTBE yet the potential for exposure due to groundwater contamination is substantially lower. Because exposure to these potent aromatic compounds in the air is already high, increases in the aromatic content of gasoline represent a public health threat.

MTBE has been shown to produce cancer in laboratory animals. To date, however, expert panels reviewing the results of scientific studies have considered these animal data insufficient to classify MTBE as a human carcinogen. In a situation of documented animal carcinogenicity and equivocal evidence of human carcinogenicity, the conservative public health approach used by the northeast states is to treat MTBE as a carcinogen for comparative risk purposes. However, it should be stressed that NESCAUM has not performed any independent analysis that demonstrates that MTBE is a human carcinogen. Available data do suggest that if it is a carcinogen, MTBE is a significantly less potent than other gasoline-related pollutants such as benzene or 1,3-butadiene.

With respect to non-cancer effects, some individuals report adverse health effects following short-term exposure to MTBE. The health effects reported, include: headaches, dizziness, and eye and throat irritation. However, limited studies to date have not been able to confirm that MTBE exposure is causally associated with significant increase in these symptoms in the general population. The federal Office of Science and Technology Policy concluded that “[a]necdotal reports of acute health symptoms among some individuals at very low levels of exposure to oxygenate cannot be adequately explained, but cannot be dismissed.”¹⁷ Further analyses of the short-term reaction to MTBE exposure is necessary, particularly in self-reporting sensitive members of the population to better qualify and quantify this potential effect.

¹⁷ *Interagency Assessment of Oxygenated Fuels*, National Science and Technology Council, 1997.

The general public is potentially exposed to MTBE and other gasoline constituents and combustion by-products through various pathways including breathing outdoor and indoor air and drinking or using contaminated water. Existing data suggest that typical ambient air concentrations of MTBE do not pose a chronic public health threat in the Northeast. The chronic threat posed by MTBE appears limited to those subpopulations exposed to elevated airborne MTBE concentrations and who live in households with drinking water containing concentrations greater than state public health guidelines. Northeast state health guidelines range from 35 to 70 micrograms per liter. By contrast, ambient air concentrations of benzene exceed health protective thresholds in all locations in the Northeast. The additional exposure for individuals living in households with drinking water containing concentrations of benzene greater than state public health guidelines (5 micrograms per liter) will increase the threshold exceedance by over two orders of magnitude. Based on the initial exposure assessment conducted by NESCAUM, the presence of Stage II vapor recovery systems at the gasoline refueling pump, would reduce the total MTBE exposure such that only the upper bound exposure scenario would exceed the health protective threshold.

Public health agencies in the Northeast states use available scientific evidence to develop health-protective thresholds for compounds in multiple environmental media. These health-protective thresholds are not absolute indicators of anticipated adverse health impact following exposure, but rather represent exposure concentrations that are expected to result in no adverse health effects with long-term exposure. Thresholds aid in screening environmental contaminants of potential concern in order to target additional emission reduction efforts and to identify areas requiring more refined assessment of potential health impact.

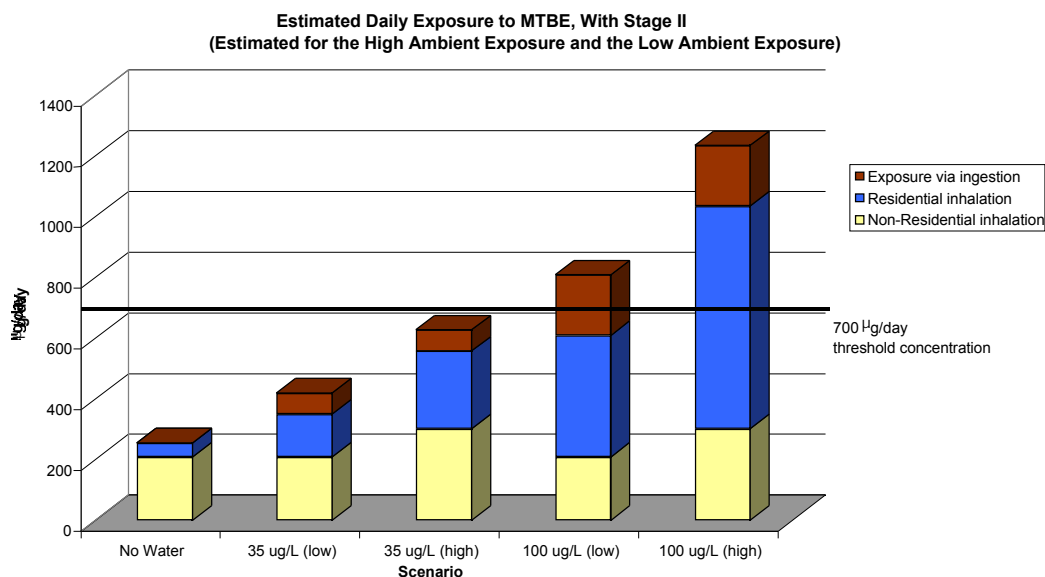
In order to understand the differences in exposure and the attendant health risk(s), NESCAUM evaluated several exposure scenarios.¹⁸ Figure 2 indicates the relative importance of the various exposure routes. The figure includes exposure estimates for individuals with and without MTBE-contaminated water. High and low estimates are provided for two different levels of water contamination. The high/low values within each water contamination level represent the maximum and minimum measured MTBE concentrations in homes.^{19,20} The use of these estimates is intended to bound the uncertainty regarding exposure to MTBE vapors inside the residence. In the program recommendations herein, NESCAUM recommends a regional monitoring and exposure assessment program. This program would support a more comprehensive exposure assessment and distributional exposure analysis, which would provide more precise estimates of the portion of the population at different risk levels in the Northeast.

¹⁸ Please refer to the technical paper for more complete details regarding exposure scenarios evaluated.

¹⁹ Huber, A.H. Human Exposure Estimates of Methyl Tertiary Butyl Ether (MTBE). Abstract and presentation for the Conference on MTBE and other Oxygenates, Falls Church, VA, July, 1993.

²⁰ Brown, S. L. 1997 Atmospheric and Potable water exposures to methyl tert-butyl ether (MTBE). *Regulatory Toxicology and Pharmacology* 25: 256-276.

Figure 2



The presence of MTBE-contaminated water is predicted to increase overall exposure by 50 to 300 percent, depending on the concentration of this pollutant in the water and the assumptions about outdoor and residential exposure. Figure 2 also shows the public health threshold (700 micrograms per day) designed to protect the average individual against adverse effects of MTBE exposure, including potential cancer effects, as described previously. These results suggest that the presence of contaminated water may be sufficient to increase average individual exposures to levels above the health protective threshold.

As discussed previously, monitoring and modeling studies indicate that mobile source-related pollutants are currently driving a significant portion of the overall public health risk from ambient air toxics. Results from the computer modeling conducted as part of the USEPA's CEP indicate the size and scope of the potential public health threat associated with exposure to airborne toxins in the outdoor air. Some toxins, including benzene and other gasoline-related pollutants, are predicted to exceed health protective thresholds in every census tract in the country. Consequently, it is critical that there be no backsliding with regard to air toxic emissions from gasoline as we look for ways to better protect water resources. It would be shortsighted to relinquish cost-effective toxic reductions from RFG as the need for greater overall toxic reductions becomes increasingly apparent.

PROGRAM RECOMMENDATIONS

Overview

NESCAUM proposes a multi-component strategy for the northeast states to cost-effectively reduce the adverse impacts of MTBE on water resources, while maintaining the public health benefits of the RFG program. The strategy includes: regulatory initiatives; a monitoring and assessment program: rigorous scientific assessments of the cost, supply, and health impacts of MTBE alternatives; and a public education and outreach campaign. In light of the fact that RFG and the oxygenated fuels program are federal initiatives, NESCAUM believes that a federal solution is warranted and optimal. To this end, the northeast states must continue to work with other interested parties to develop and implement an effective and equitable national solution. Absent an appropriate federal response, a regional solution will be pursued in the Northeast.

Legislative and Regulatory Initiatives to Reduce MTBE in Gasoline

As evidenced by the conclusions of the Federal Blue Ribbon Panel, there is broad agreement that the amount of MTBE used in reformulated gasoline should be reduced to lower the risk of water contamination. While the goal is straightforward, the process for achieving this objective is complex. Several statutory and regulatory impediments must be overcome to achieve the desired outcome. Because federal action is needed to change the Clean Air Act and modify existing USEPA regulations, the northeast states must remain active participants in the national debates. The following steps need to be taken to affect a reduction in MTBE use. Depending on the outcome of on-going negotiations in Congress, either the federal government or states may ultimately implement various elements of this strategy.

Removal of the Oxygen Mandate for the Federal RFG Program

The NESCAUM strategy to reduce MTBE use in the Northeast hinges on Congressional action to lift the Clean Air Act requirement that RFG contain a minimum of 2 percent oxygen by weight (11% MTBE by volume). While an across-the-board repeal of the oxygen requirement is most appropriate, the ability of states to receive a waiver of this requirement upon demonstrated need presents a second option. Unless the oxygen mandate is lifted, a reduction in the use of MTBE will force widespread use of ethanol in the Northeast. The cost-effectiveness of transporting and distributing ethanol in the Northeast remains uncertain.

Congressional Clarification of USEPA and State Regulatory Authority

Congress must clarify USEPA and individual state's authority to control or prohibit the use of fuel additives that pose an unacceptable risk to the environment. At present, USEPA and the states have authority to regulate fuel if necessary to protect public health from exposure to air pollution. However, authority is less clear when the need is environmental and not public health protection, as is the case with MTBE. States would be authorized to further regulate or eliminate MTBE by submitting a Section 211 waiver request to USEPA. NESCAUM recommends that USEPA use the criteria outlined by the federal Blue Ribbon Panel to evaluate state waiver requests regarding the control of MTBE.²¹ For RFG

²¹ The Panel Report Recommends a two-part test for use in acting on a state waiver request to restrict or eliminate MTBE: (1) states must demonstrate that their water resources are at risk from MTBE use and (2) states have taken the necessary measures to restrict or eliminate the presence of gasoline in the water resource. To maximize

areas granted a waiver, the Phase II RFG performance standards would remain federally enforceable. To minimize production, supply and cost impacts, states will seek to implement any further regulatory action regarding MTBE regionally according to a consistent schedule.

Three Year Phase-down and Cap on MTBE in Gasoline

USEPA and the states should work together to assess the necessary reductions in MTBE levels to mitigate the unacceptable risk to water resources. Within six months of Congressional action lifting the mandate, the USEPA should propose regulations to phase-down and cap the MTBE content of all fuels. The cap should be phased-in over a three-year period to minimize adverse economic impacts and must apply to all grades of gasoline sold in the U.S. year-round to ensure that overall MTBE use is reduced, not just diverted to the conventional gasoline pool. If USEPA fails to act in a timely manner, the northeast states will employ the federal authority described above to phase down and cap MTBE within three years.

After the phase-down is complete and the cap is in place, the northeast states will collaboratively assess whether additional federal, regional or state actions are necessary to protect water resources from MTBE contamination. Based on this assessment, individual states or the region may further regulate the MTBE content of gasoline. State or regional action must balance the benefits of uniformity in fuel quality requirements against the differential risk to water resources posed by MTBE in the NESCAUM member states.

USEPA Action to Prevent Air Quality Backsliding

The air toxic benefits currently realized from RFG (i.e., a 35% in mass emissions of the five regulated toxins in the Northeast market in 1998) must be sustained under the Phase 2 RFG program. To accomplish this goal, USEPA must revise the Phase 2 RFG performance standard for toxics to ensure that the 1998 annual average in the Northeast continues to be achieved after January 1, 2000. In addition, toxic air emissions from conventional gasoline sold in the Northeast have declined 13% since 1990, and those emission benefits should also be preserved through additional federal regulation. Allowing the use of lower levels of MTBE in the near-term will assist gasoline refiners in meeting this standard in a cost-effective manner.

Regional Assessment of Gasoline Storage Tank Leak Protection Programs

Leaking gasoline storage systems represent the primary pathway for gasoline to enter groundwater supplies. There are approximately 1.1 million federally regulated underground storage tanks in the U.S.; the overwhelming majority contain petroleum.²² In 1988, USEPA issued regulations establishing minimum standards for new tanks and requiring owners of existing tanks to up-grade, replace or close them. Full compliance with the UST requirements was to occur within ten years of promulgation. The UST regulations are designed to prevent releases of stored petroleum and chemical products into the

uniformity and minimize economic impacts the Panel recommends that USEPA establish criteria for state waiver requests including but not limited to: (a) water quality metrics necessary to demonstrate the risk to water resources and air quality metrics to ensure no loss of benefits from the RFG program; (b) compliance with federal requirements to prevent leaking and spilling of gasoline; (c) programs for remediation and response; and (d) a consistent schedule for state demonstrations, USEPA review, and any resulting regulations of the volume of gasoline components in order to minimize disruption to the fuel supply system.

²² UST Program Facts: Implementing Federal Requirements for Underground Storage Tanks, U.S. Environmental Protection Agency's Office of Underground Storage Tanks (EPA 510-B96-007, December 1996).

environment through tank upgrades and on-line monitoring of tank and piping integrity.

These programs cover commercial gasoline and chemical storage tanks with at least 10 percent of their combined volume underground. Non-commercial farm and residential underground tanks with a capacity of less than 1100 gallons are exempt from the UST program. Any tank with a capacity of less than 110 gallons is also exempt. Above ground tanks are not covered by UST requirements. Although substantial progress has been made in implementing UST programs, nationally, 20 percent of applicable tanks have not been upgraded. However, compliance rates in the Northeast are better than the national average. Data for the New England states show that 96 percent of regulated tanks and systems have been upgraded.²³

NESCAUM recommends that the northeast states conduct an analysis of the need for and viability of regulating gasoline storage systems not covered under existing UST programs. This would include exempted underground systems and above ground gasoline storage tanks. If additional controls are deemed viable and cost-effective, the northeast states should expeditiously initiate rulemakings to regulate the expanded universe of gasoline storage systems. We also recommend an evaluation of the UST program in the region to assess opportunities for augmenting enforcement and compliance programs and expediting full implementation of these regulations. As part of the feasibility analysis the northeast states must assess the additional regulatory costs associated with any significant program expansions.

Regional Multi-Media Monitoring and Assessment Program

The northeast states should collaborate in the development of an enhanced air and water quality monitoring and assessment program. The primary goals of the initiative are to: (1) enhance our understanding about concentrations of gasoline-related toxins, including MTBE, in the region's air and water and (2) track the environmental impacts associated with reducing MTBE use and substituting other octane enhancing constituents in gasoline. The first step in undertaking this enhanced monitoring and assessment initiative is to identify public and private resource needs and availability.

A regional taskforce will be established to develop an environmental media monitoring and assessment plan, which will include appropriate data quality objectives, target pollutants, measurement methodologies, and analytical techniques. Effort will be made to ensure that proposed ambient monitoring efforts expand upon ongoing state activities, such as the photochemical assessment monitoring stations (PAMs) and water quality monitoring programs. The Commonwealth of Massachusetts has developed methodologies to accurately determine volatile petroleum hydrocarbons in soil, water, and air and to comparatively assess the risk of complex mixtures of petroleum hydrocarbons in air or water.^{24,25} These methodologies will be used as starting points to establish the technical elements and scope of the environmental media monitoring and assessment plan.

There is little long-term data on historical levels of MTBE in the air and water in the Northeast. Most

²³ FY 99 Supplemental Activities Report, U.S. Environmental Protection Agency Office of Underground Storage Tanks, May 1999.

²⁴ Method for the Determination of Volatile Petroleum Hydrocarbons. Massachusetts Department of Environmental Protection, Division of Environmental Analysis, Office of Research and Standards, Bureau of Waste Cleanup, January 1998.

²⁵ Interim Final Petroleum Report: Development of Health-Based Alternative to the Total Petroleum Hydrocarbon (TPH) Parameter, Massachusetts Department of Environmental Protection, Office of Research and Standards, 1994.

states in the Northeast are now testing for MTBE as part of their routine water quality monitoring programs and are initiating airborne measurement of this pollutant. NESCAUM recommends that all states in the region add MTBE to the current suite of VOCs analyzed as part of their public and private drinking water monitoring programs. Further, states should assess and enhance, as necessary, existing water quality monitoring efforts. It is essential that the northeast states adopt consistent measurement, analysis, and reporting requirements to enable the development of a regional database on waterborne MTBE contamination. In order to assess the long-term impacts of reduced MTBE concentrations in fuel, NESCAUM recommends that the region undertake a limited number of focused surface, ground, and drinking water quality monitoring projects. These projects should assess geologically diverse “high risk” locations (e.g., fuel stations, bulk distribution terminals, UST locations, and spill sites).

The Northeast states will initiate a process involving state environmental and public health officials to establish regionally consistent health-protective thresholds for MTBE in air and water that will be used to assess the public health impact of this compound. Additionally, the northeast states believe that USEPA should, at a minimum, develop an interim maximum contamination level (MCL) to establish a consistent national standard.

The regional monitoring and assessment program and the regionally-consistent health-protective thresholds will inform future regulatory and programmatic decisions, including the need to reduce MTBE beyond the levels established by federal or state caps. It will also help to quantify the public health benefits associated with the air toxic reduction element of the federal RFG program by providing both direct measurements and the data needed to validate computer models that predict public exposure to gasoline-related toxins. The data from this assessment will serve to verify the Northeast’s commitment to no “backsliding” with regard to the air toxic benefits of the RFG program.

To the extent that ethanol or other oxygenates begin to penetrate the Northeast market in significant quantities, states should monitor for these alternative oxygenates. NESCAUM recommends that this compound be added to the list of target pollutants in the regional measurement and assessment program at this time. These data will help establish a viable baseline from which to compare future changes should ethanol be widely introduced in the coming years. In addition to direct contamination of groundwater, the presence of ethanol could result in collateral effects. For example, the magnitude of benzene contamination could increase because the microbes that currently biodegrade benzene may be preferentially attracted to ethanol where it is present. The availability of baseline data might help regulators better understand the relationship between ethanol and benzene.

Scientific Assessment of MTBE Alternatives

Should changes to the RFG program result in the decision to substantially increase the use of a gasoline constituent or additive, a rigorous multi-media assessment must be undertaken to proactively assess potential public health and environmental impacts. Specifically, research is needed on the health effects and environmental behavior of likely MTBE substitutes including ethanol, alkylates and various aromatic compounds. It is important to look both at these constituents alone and as part of the gasoline mixture.

The unanticipated degree of adverse impacts of MTBE on water resources provides a powerful example of the need to study the potential impacts of new gasoline products on air, water, and soil, as well as the need to understand the effect of dramatically increasing any current constituents of gasoline. Changes to the RFG program will by design or necessity result in substantial increases in the use of existing

gasoline constituents or the introduction of new additives. NESCAUM recommends that USEPA work with the states to develop a basic screening process that must be completed prior to the introduction of new fuel constituents. This screening process must include an assessment of environmental fate and transport and a structure-activity assessment. The existing toxicity testing requirements established under Section 211(b) of the Clean Air Act must be streamlined to enable more timely assessment of potentially adverse health impacts of gasoline constituents. NESCAUM recommends that USEPA require fuel manufacturers to use readily available and accepted protocols to assess the various toxicity endpoint established under the Standard and Alternative Tier II testing requirements. Moreover, NESCAUM recommends that more rigorous multi-media assessments be undertaken to assess potential long-term public health and environmental impacts of MTBE substitutes.

Analysis of the Fuel Supply and Price Impacts of Reduced MTBE Usage

Detailed refinery modeling and supply and distribution analyses should be completed to predict how changes in fuel formulations will affect the cost of producing gasoline for the Northeast market. While the U.S. Department of Energy (USDOE) has analyzed the cost and supply impacts of removing MTBE from RFG, no studies have been completed to assess the impacts associated with a maximum cap of MTBE levels. Further, USDOE modeling has assumed that refiners would only meet the minimum regulatory requirements for toxic air emissions. Existing modeling does not assess supply and distribution issues associated with MTBE alternatives. NESCAUM recommends that additional studies be conducted to look at the cost impacts of producing RFG for the Northeast that meets the proposed 35 percent toxic performance standard for Phase 2 RFG.

To better understand the cost of phasing down or eliminating the use of MTBE in gasoline in the Northeast while preserving the substantial margin of overcompliance experienced to date from the RFG program, NESCAUM recommends four additional refinery modeling runs as described in the footnote.²⁶ All analyses should include both the RFG and conventional gasoline pools.

²⁶ **Reference Case:** The 35% reduction in air toxics as achieved under the MTBE-based RFG program in the Northeast in 1998. Include PADD I and PADD III refineries. Separate the RFG and CG pools, and regular and premium grades. When ethanol is used during a particular season, it must be used for the entire pool in order to avoid commingling.

Cases

1. All parameters used in the reference case, but no oxygenates in either the RFG or the CG pools. This case represents a worse case scenario. It assumes that the oxygenate mandate is lifted, ethers are banned, and ethanol is, for whatever reason, not available. This case will quantify the tradeoff between motor vehicle toxic emissions, gasoline price, and oxygenates.
2. All parameters used in the reference case, an MTBE cap of 3%, and 5%, by volume for the pool average, including RFG and CG, regular and premium. Refineries are free to use various amounts of MTBE in different pools or grades.
3. All parameters used in the reference case, but lift the oxygenate mandate. US DOE performed a similar scenario but only for an immediate case without investment. This case differs from the DOE scenario because it allows for investment, and will include PADD III as well as PADD I.
4. All parameters used in the reference case, maintain the oxygenate mandate, ban ethers, for PADDs I and III. US DOE has already completed an analysis of this scenario, but only for PADD I, and the reference case has changed significantly.

Public Education and Outreach Initiative to Diminish Gasoline Spillage

Enormous amounts of gasoline are spilled each year at the gas station pump, during transport, and while refueling small engines such as those used to power lawn and garden equipment and recreational vehicles such as boats and snowmobiles. These spills have a host of adverse impacts including air, water and soil contamination. The presence of high concentrations of MTBE in RFG has increased the threat to groundwater supplies from these small-scale spills.

The northeast states, in conjunction with other interested parties, have embarked on a sustained public outreach campaign designed to reduce the number and magnitude of spills associated with the improper handling of gasoline. This campaign promotes better care among consumers and cost-effective technological solutions to minimize the occurrence of small-scale spills. To this end, NESCAUM has established a partnership -- The Alliance for Proper Gasoline Handling -- to initiate a national education and outreach campaign. In addition to the NESCAUM states, the alliance currently includes representatives from the oil industry, oxygenate manufacturers, USEPA, California Air Resources Board and environmental advocates. These efforts must be sustained and expanded in the coming years.

CONCLUSION

This study demonstrates that federal and state decisions regarding gasoline fuel quality can have a significant impact on environmental quality, public health and the region's economy. The recommendations presented in this report chart a course for state and federal action to aggressively mitigate the environmental risk posed by MTBE while maintaining the public health benefits of the RFG program. In addition, the proposed effort to better characterize the environmental and public health impacts of gasoline constituents and MTBE alternatives will begin to provide the knowledge needed to responsibly direct future changes in the fuel supply.

The keystone of these recommendations is securing the flexibility and clear authority to regulate gasoline constituents and additives that pose an unacceptable risk to natural resources. Toward this end, the northeast states must continue to advocate for Congressional action to lift the oxygen standard within the federal RFG program and expand Section 211 authority for regulating gasoline additives. History demonstrates that regional coordination among the northeast states results in protective and cost-effective environmental policies. Given the opportunity to act on these recommendations, the northeast states will again succeed in helping to provide the citizens of the region with the air and water quality protection they deserve.

Northeast States for Coordinated Air Use Management

Attachment I

**The Health Effects of Gasoline
Constituents**

August 1999

Table of Contents

SUMMARY	4
<u>I. INTRODUCTION</u>	<u>6</u>
<u>II. BACKGROUND</u>	<u>7</u>
<u>III. FACTORS AFFECTING TOXICITY AND AIR QUALITY IN THE NORTHEAST:</u>	<u>8</u>
A. REGULATORY GUIDELINES AND STANDARDS FOR MTBE AND OTHER GASOLINE CONSTITUENTS:	9
B. AMBIENT AIR QUALITY AND CONCENTRATIONS OF GASOLINE-RELATED POLLUTANTS IN THE NORTHEAST :	16
C. AIR QUALITY CHALLENGES IN THE NORTHEAST:	18
<u>IV. OVERVIEW OF MTBE HEALTH EFFECTS:</u>	<u>20</u>
A. GENERAL EFFECTS	20
B. CANCER	21
C. SHORT-TERM, REVERSIBLE EFFECTS	21
D. OTHER EFFECTS OF MTBE	22
<u>V. TOXIC EFFECTS OF OTHER MTBE SUBSTITUTES:</u>	<u>23</u>
A. OXYGENATES	23
ETHANOL AS A SPECIAL CASE OXYGENATE	23
B. OTHER GASOLINE ADDITIVES	25
“ALKYLATE” AND AROMATICS	26
<u>VI. TESTING OF FUEL PRODUCTS AND ADDITIVES</u>	<u>27</u>
<u>VII. MULTI-MEDIA EXPOSURE TO MTBE AND OTHER GASOLINE CONSTITUENTS</u>	<u>29</u>
A. HEALTH-PROTECTIVE THRESHOLDS	29
B. THRESHOLD DETERMINATION FOR INITIAL COMPARATIVE EXPOSURE ASSESSMENT	29
C. NESCAUM’S COMPARATIVE EXPOSURE ANALYSIS	31
HUMAN CONTACT WITH MTBE:	31
ANALYSIS OF EXPOSURES:	31

VIII. IMPORTANT DATA LIMITATIONS	35
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IX. ARTICLES REVIEWED AND REFERENCES CITED	36
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The Health Effects of Gasoline Constituents

August 1999

Summary

Gasoline powered vehicles emit about one-third of smog-forming volatile organic compounds (VOCs) and oxides of nitrogen (NO_x) in the Northeast Region. Nationally, air quality monitoring data demonstrate that the clean fuel programs such as oxyfuel and reformulated gasoline (RFG) have succeeded in reducing ambient levels of ozone smog, carbon monoxide, and other hazardous air pollutants (HAPs) including benzene, a known human carcinogen (CARB, 1998; National Research Council, 1999). In the Northeast, continued exceedances of the National Ambient Air Quality Standard (NAAQS) for ozone and unacceptable ambient concentrations of numerous cancer causing agents, underscore the need for clean fuel programs.

At present, MTBE does not pose a significant health risk to the general population. For the population as a whole, the public health benefits RFG provides by reducing air pollution substantially outweigh adverse health impacts from exposure to increased levels of the oxygenate methyl tertiary butyl ether (MTBE) in the air and water. This conclusion stems largely from the fact that many of the toxins reduced through the use of RFG are far more potent than MTBE and that tens of millions of Northeast residents benefit from ozone reductions and reduced vehicle air toxic emissions, while MTBE-contaminated drinking water effects a relatively small percentage of Northeast residents. However, the objective of environmental protection programs is to mitigate all environmental and public health risks, including protection of small, disproportionately affected or sensitive sub-populations. Therefore, despite the benefits of the RFG program, the adverse water quality impacts associated with the increased use of the oxygenate MTBE, have led to questions about the merits of this program. To fully assess the complicated issue of air quality benefits, water quality costs, and inclusive public health protection, it is necessary to consider impacts on both environmental media, the potency of the compounds, and potential for exposure to the various constituents of fuels.

Gasoline is a mixture of highly toxic chemicals. Recognizing that the nation is reliant upon the use of gasoline, the challenge facing environmental regulators is to determine how this chemical mixture can be reformulated to lower its toxicity (potency), avoid exposure, and improve the quality of both air and water resources. This report assesses the public health consequences of unhealthy air quality and the comparative risk of MTBE and other gasoline constituents and combustion products. We also analyze available information on likely near-term substitutes to MTBE. In some cases, existing data on potential MTBE alternatives are inadequate to perform meaningful risk comparisons. Prior to a change in the fuel supply that results in the addition of new compounds or a substantial increase in existing fuel components, rigorous analysis of environmental fate, transport, and potency of the constituents and mixture must be conducted.

The tension formed between public health protection and environmental resource protection with the use of MTBE in the clean fuels program is relatively unusual. Generally, compounds that pose substantial environmental risk are similarly detrimental to public health. In this traditional dynamic, the obvious pathway for regulatory action is to diminish the use of such compounds to the greatest extent possible. The complex challenge presented by MTBE is that air quality benefits have occurred with a concurrent adverse impact on water quality. The scenario now facing policy makers, is the reality that the alternative to gasoline with MTBE is gasoline without MTBE. If MTBE is reduced or eliminated from the fuel supply, gasoline producers will be forced to add other compounds to make up for the lost volume and octane provided by MTBE. Many of these compounds are highly toxic or have been subjected to limited scientific evaluation. This report seeks to provide policy makers with the available public health data necessary to effectively balance these difficult choices. Additionally, the technical paper identifies existing data gaps, which will undermine effective policy making.

The following conclusions were drawn from this assessment:

1. Ambient concentrations of fuel components and combustion by products such as acetaldehyde, benzene, 1,3-butadiene, and formaldehyde exceed health-protective threshold concentrations across all locations in the Northeast.
2. Ambient concentrations of MTBE do not exceed health protective thresholds.
3. Due to differential potencies, exposure scenarios of concern differ for benzene and MTBE.
 - Benzene exposure estimates exceed total daily health protective threshold concentrations based solely on outdoor ambient exposure assumptions. Residential exposure, where contaminated drinking water is present, essentially doubles the estimated exposure.
 - MTBE exposure estimates exceed total daily health protective threshold concentrations when the following assumptions are made: 1) no Stage II vapor recovery is in use at the refueling pump, 2) residential drinking water concentrations of MTBE are greater than 35 µg/L, 3) ambient MTBE concentrations are approximately 10X the highest monitored in the Northeast region, and 4) the residence has an attached garage.
4. MTBE is an animal carcinogen, but has not been listed as a human carcinogen
 - Available data suggests that if it is a cancer hazard in humans, MTBE is 7X less potent than benzene and 25X less potent than 1,3-butadiene.
5. MTBE has a low taste and odor threshold. In some cases this will aid in recognition and reduction of exposure. However, the taste and odor thresholds of this compound are not adequate warning properties for the entire population, given the variability of individual responses.
 - Evidence in the Northeast suggests that many individuals don't detect MTBE until concentrations in drinking water are well above 100 µg/L.
 - The "turpentine-like" taste of this additive can make drinking water unacceptable to consumers, regardless of possible health effects.
 - The ability to smell MTBE in the air may be the cause of actual or perceived acute health impacts for a sensitive segment of the population.

- Other ethers share the MTBE's taste and odor characteristics.
- 6. Current environmental concentrations of MTBE do not appear to result in short-term adverse health impacts in the general population.
 - Sensitive individuals report acute health effects including headaches, dizziness, and eye and throat irritation.
 - To date, scientific evidence has not been able to adequately confirm or dismiss these reported acute effects.
 - There is currently insufficient, peer reviewed, scientific information to evaluate assertions that MTBE exposure is associated with increasing rates of asthma incidence.
- 7. Use of ethanol, as a gasoline supplement will increase the combustion by-product emission rate of acetaldehyde, a probable human carcinogen, in the Northeast by between 50-70%. Ambient levels currently exceed health-protective thresholds at a majority of monitoring locations in the northeast.
- 8. A paucity of peer-reviewed scientific information exists regarding the potential short or long-term human health effects associated with exposure to "alkylate," a generic term for a group of C₅-C₁₀ isoparaffins, used as an octane enhancer in place of MTBE.
- 9. In general, existing public health testing requirements for gasoline components and additives are inadequate. A streamlined risk screening process, which accounts for environmental fate and transport and is supplemented by a more timely evaluation of multiple toxicity endpoints, must be performed prior to the widespread use of new additives. In the absence of these necessary analyses, it is impossible to confidently protect public health and environmental quality from future changes in the fuel supply.

I. Introduction

MTBE has been used as an octane enhancer in gasoline since lead was phased-out in the late 1970's. The amount of MTBE used in gasoline has increased considerably during the 1990's with the introduction of oxygenated fuel and RFG, constituting about 15% of oxygenated gasoline (oxyfuel) and 11% of RFG by volume. The presence of increased volumes of this compound has instigated a host of public concerns. These concerns have included: adverse acute health effects following exposure to MTBE in gasoline vapors and from drinking water, the relative cancer risk associated with exposure to MTBE, and the potential link between exposure to MTBE and the increased asthma rates in urban communities. To date, a causal association between exposure to MTBE and occurrence of adverse health effects has not been statistically established through scientific research.

The health hazard that a compound poses to a population is a function of: 1) the number of people exposed; 2) the magnitude of the exposure; and 3) the length of the exposure. This document provides a qualitative and quantitative assessment of the risks posed by the various compounds in gasoline. Additionally, this report assesses the potential health hazard associated with multi-media exposure to low-level ambient concentrations of MTBE and benzene as well as higher exposures encountered following gasoline spills

and leaks which impact drinking water supplies. The health effects of other gasoline constituents or combustion products are also discussed and compared to those of MTBE and benzene. This analysis suggests that several fuel components and combustion by-products reach levels of public health concern in both air and water in the Northeast. The potential human health risks are more pronounced for the more potent gasoline-related air toxins such as benzene and 1,3-butadiene than for MTBE.

This paper summarizes the current state of knowledge regarding the cancer and non-cancer risk health effects of MTBE and other gasoline-related pollutants, the potential for exposure to these compounds, and the advantages and disadvantages of the RFG program for both air and water resources. The toxic actions of MTBE and several other gasoline components evaluated in this analysis include: 1) potential cancer risk; 2) short-term, reversible adverse health effects (dizziness, nausea, headache); 3) respiratory irritation; and 4) taste and odor detection limits in air and water.

A number of detailed analyses covering the “state of science” regarding the potential health and environmental impacts of MTBE have been published in recent years. This technical paper draws heavily from those previous studies, developing a qualitative, comparative assessment of the potential health hazard of MTBE and benzene in ambient air and drinking water. This analysis is intended to help inform Northeast decision-makers regarding the appropriate policy to maximize the public health benefits from cleaner-burning fuels while minimizing any adverse effects on public health and water resources in the Northeast.

II. Background

When gasoline evaporates or is combusted, a range of air pollutants are emitted including: ozone forming compounds (VOCs and NO_x), carbon monoxide, and other HAPs such as acetaldehyde, benzene, formaldehyde, 1,3-butadiene. The Clean Air Act Amendments of 1990 (CAA) established the oxygenated fuels and RFG programs to reduce carbon monoxide emissions and ozone-forming hydrocarbons and HAPs, respectively.

RFG has proven to be an effective strategy for reducing ozone concentrations in the Northeast and elsewhere (CARB, 1998 and National Research Council, 1999). Ozone is a powerful respiratory irritant that affects large segments of the population including the elderly, children and individuals with existing respiratory problems. Since RFG was introduced in the Northeast in 1995, ambient concentrations of several vehicle-related HAPs have also decreased substantially in the region. For example, ambient levels of benzene have declined by approximately 40%. In California, ozone reductions attributed directly to RFG use ranged between 10 and 12% (CARB, 1998).

A recent NESCAUM study evaluated the relative cancer risk of RFG and conventional gasoline (NESCAUM, 1998). This study concluded that:

1. federal RFG sold in the Northeast in 1996 reduced the cancer risk associated with exposure to gasoline vapors and exhaust by at least 12% compared to conventional gasoline;
2. benzene's contribution to the overall cancer risk was greater than the sum of the cancer risks for the other toxic compounds evaluated; and
3. the cancer potency of MTBE is 7X less than that of benzene and 25X less than 1,3-butadiene.

The earlier NESCAUM study supported the assertion that the RFG program has reduced the public health risk associated with automobile emissions.

For this technical paper, the cumulative hazard presented by MTBE and benzene in air and water are estimated under various exposure scenarios. The relative toxicity of other gasoline constituents is also described. Because real world exposures typically involve multiple compounds and transient exposures, we have aimed to identify known uncertainties or limitations of the analysis.

This initial exposure scenario comparison is intended to provide perspective in considering policy options regarding MTBE and the federal RFG program. A more thorough multi-pollutant, multi-media, distributional analysis would be appropriate to ensure a reduction in overall health risks and not simply a transferal of risk from air to water or from one sensitive sub-population to another.

III. Factors affecting toxicity and air quality in the Northeast:

The toxicity of a chemical is determined by its ability to reach and adversely affect a target site. The elements and reactions involved in this process are summarized in Table I below.

**Table I.
Factors Affecting Toxicity**

Exposure: A measure of the concentration of a compound (dose) and the length of time in contact with the compound (duration). An effort is made to identify both individual and population-based exposures in this analysis.

Route(s) of exposure: Chemicals can enter the body following inhalation, ingestion, or skin (dermal) contact. The route of exposure is an important element when assessing target organ toxicity, since the percentage of absorption of an exposure concentration will vary across these routes. For this analysis, exposure to benzene and MTBE are evaluated for ingestion and inhalation exposures only. Analyses conducted by others have demonstrated that dermal contact with volatile organic compounds, such as these, was an insignificant contributor to human exposure (Brown, 1984; McKone and Bogen, 1992).

Potential for exposure: The opportunity for an individual or population exposure to occur. This report qualifies and quantifies, to the extent possible, the types of exposure likely for the gasoline constituents compared.

Target organ: The site of toxic action for the constituents considered in this report, effects on the central nervous system (neurological effects), the organs where detoxification and excretion occurs (hepatic and renal effects), and immune system (effects such as allergy and asthma) are evaluated.

Potency: The range of concentrations over which a compound elicits an adverse effect at a target organ. The more potent a compound, the lower the concentration necessary for an adverse reaction to be observed. In this analysis, the relative potencies of the various compounds are compared to provide a basis for evaluating current and future policy options.

A. Regulatory guidelines and standards for MTBE and other gasoline constituents:

Table II identifies the regulatory and health protective threshold concentration for certain gasoline-related pollutants. These thresholds consider the target organ effect of most significant public health concern and the potency of the regulated compound. More restrictive threshold concentrations; therefore, indicate more potent toxins. For example, both 1,3-butadiene and benzene are assigned lower drinking water and ambient air standards than MTBE, indicative of the greater potential of these compounds to elicit adverse health effects. Five of the eleven compounds are designated as animal or human carcinogens and inhalation or ingestion cancer-protective concentrations have been determined. In this table, Northeast state drinking water standards are listed as well as health-protective inhalation or ingestion exposure concentrations.¹ For carcinogens, the health protective thresholds shown represent the concentration of a known, probable, or possible human carcinogen that will result in the risk of one excess cancer occurring in one million individuals (10^{-6}) exposed to that concentration for a lifetime. For adverse non-cancer health effects, the reference dose and concentration values shown represents the exposure concentration expected to present no deleterious non-cancer effects during a lifetime of continuous exposure.

Table III shows the taste and odor thresholds for several gasoline constituents and combustion by-products. The information in these tables indicates that MTBE, although one of the least potent toxins in gasoline can be smelled and tasted at extremely low concentrations in air or water. However, given the wide range in individual variability in odor and taste thresholds for MTBE, it is possible that individuals could be exposed above a health protective threshold concentration without awareness. Recent experience in Northeast State public health agencies suggest that the majority of the population cannot smell or taste MTBE in drinking water at a concentrations less than 100 µg/L.

¹ The most restrictive Northeast State drinking water standard is listed, some state-to-state variation may exist in these limits.

This information suggests that the previously demonstrated odor/taste thresholds for MTBE shown in Table III (Keller *et al*, 1998) may overestimate the odor and taste detection sensitivity for the general population. It is clear that for some of the more potent compounds, i.e. benzene, exposure will routinely exceed the risk-protective threshold without detection².

These tables illustrate that complex mixtures like gasoline contain individual constituents that vary widely in toxicity. In order to assess the potential health hazards associated with multi-media exposure to low-level ambient concentrations as well as higher exposures encountered during refueling or within the residence where contaminated water is present, it is necessary: 1) to identify the toxic effect of greatest relevance/importance; and 2) to evaluate the potency of each compound.

² Note that the taste and odor thresholds shown for benzene in Table III exceed the regulatory thresholds shown in Table II.

Table II³.
Comparison of Multiple Regulatory and Health Protective
Threshold Concentrations for Gasoline Constituents and Exhaust Products

Compound	Northeast state drinking water limit µg/L (ppb)	EPA Reference Concentration ⁴ µg/m ³	EPA Reference Dose ⁵ µg/kg/day	EPA Cancer Classification	Inhalation 10 ⁻⁶ Cancer Risk Concentration µg/m ³ (air)	Ingestion 10 ⁻⁶ Cancer Risk Concentration µg/L (ppb) (water)
Gasoline Constituents:						
· Benzene	5	71 ⁶	N/A	Group A- Known Human	0.13-0.45	1
· Ethyl benzene	700	1000	100	Group D- Not Classifiable	N/A	N/A
· Toluene	1000	400	200	Group D- Not Classifiable	N/A	N/A
· Xylene	10,000	300 ⁶	2000	Group D- Not Classifiable	N/A	N/A
Oxygenates:						
· Ethanol	N/A	N/A	N/A	N/A	N/A	N/A
· MTBE	35	3000	N/A	N/A	6 [*]	
Other Octane Enhancers:						
· Alkylate	N/A	N/A	N/A	N/A	N/A	N/A
Important Emission Products:						
· Acetaldehyde	N/A	9	N/A	Group B2- Probable Human	0.5	N/A
· Acrolein	N/A	0.02	N/A	Group C- Possible Human	N/A	N/A
· 1,3-butadiene	0.019	8 ⁶	N/A	Group B2- Probable Human	0.004	N/A
· Formaldehyde	N/A	3.6 ⁶	200	Group B1- Probable Human	0.08	N/A

* USEPA, Draft document for the assessment of hazards of MTBE (National Science and Technology Council), 1996

³ Values available from the Environmental Protection Agency's Integrated Risk Information System (IRIS), unless otherwise noted.

⁴ Reference Concentration (RfC) -- An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious non-cancer effects during a lifetime.

⁵ Reference Dose (RfD) -- An estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

⁶ Caldwell, *et al.*, Toxicology and Industrial Health, Vol. 14, No. 3, 1998, pp.429-454.

Table III⁷.
Taste and Odor Thresholds for Various Gasoline Constituents.

Compound	Taste Threshold in Water (ppm)	Odor Detection Threshold (ppm)
Gasoline Constituents:		
· Benzene	0.5 - 4.5	1.53
· Ethyl benzene	-	0.46 - 2.3
· Toluene	-	8
· Xylene:		
<i>mixed isomers</i>	-	1
<i>m-isomer</i>	-	3.7
<i>o-isomer</i>	-	0.17
<i>p-isomer</i>	-	0.47
Oxygenates:		
· Ethanol	-	49 ⁸
· ETBE	0.047 ⁹	0.013 ⁹
· MTBE	0.0025 - 0.680 ¹⁰	0.053 ⁹
· TAME	0.128 ¹¹	0.027 ¹¹
· TBA	-	21 ¹²
Other Octane Enhancers:		
· Alkylate		
Important Emission Products:		
· Acetaldehyde	-	-
· Acrolein	-	0.16
· 1,3-butadiene	-	0.025
· Formaldehyde	50	0.5-1.0

For this document, the patterns of toxicity for MTBE and several other gasoline constituents or combustion by-products were compared. Alternative gasoline additives are not presented in the following figures as this text is intended to characterize the health effects of gasoline and gasoline containing MTBE narrowly. The toxicity associated with exposure to alternatives to MTBE will be discussed later in the text. Figures 1 and 2 show the adverse health effects in multiple species, at multiple target sites following acute (<14 day) and chronic (>365 day) exposures via inhalation. Because some toxic actions are irreversible (severe damage to the central nervous system) while others may produce immediate but transient responses (irritation), it is necessary to consider each relevant toxic endpoint separately. The concentration (dose) of each compound is shown on the y-axis of these figures, and the various target organs are shown on the x-axis. In both figures, the compounds at the top of the y-axis would be considered “less potent”

⁷ Reference, unless otherwise noted: Toxicological Profiles for listed compounds.

⁸ May, 1996

⁹ TRC Environmental Corporation, 1993.

¹⁰ Keller *et al.*, 1998

¹¹ American Petroleum Institute, 1993.

¹² Health Effects Institute, 1996

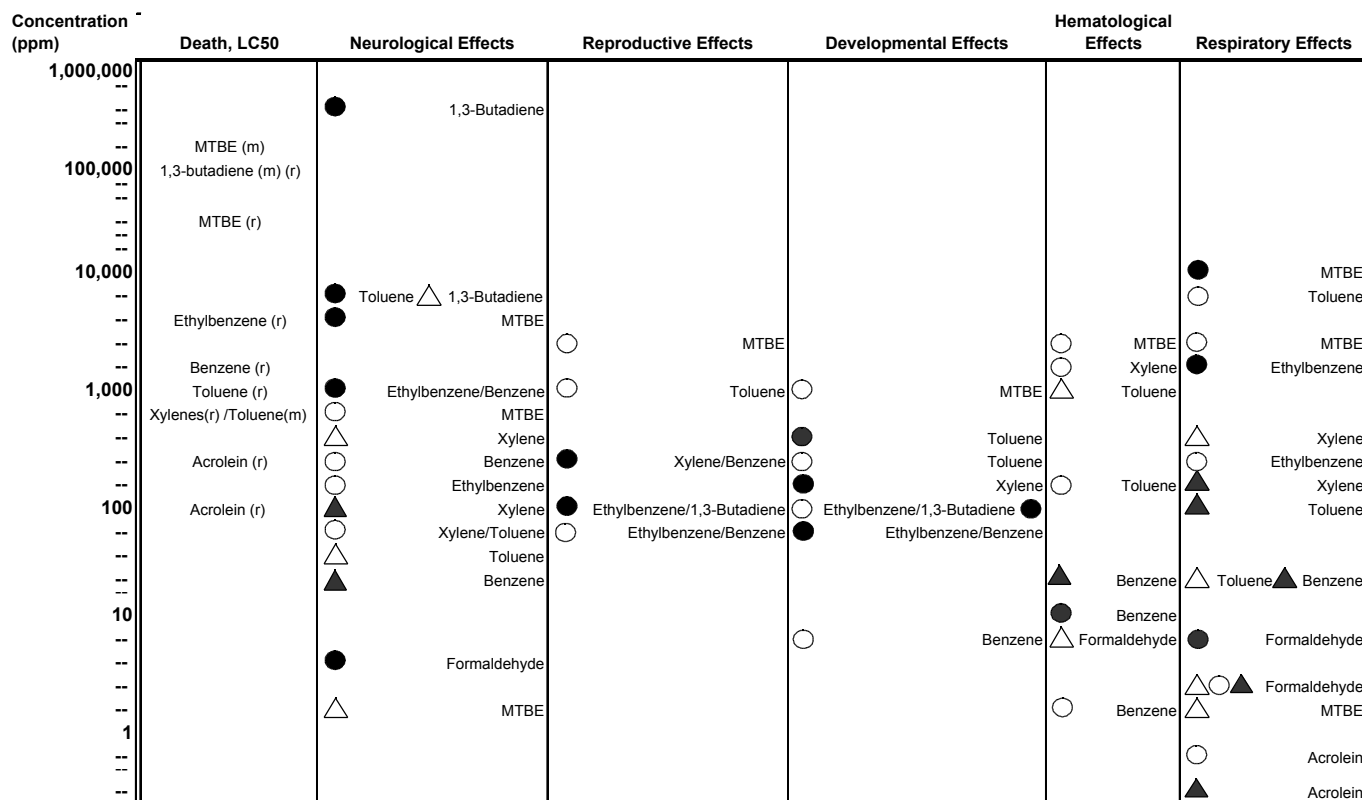
than others in the column, since higher doses are necessary to elicit the same target organ effect for compounds shown at the lower end of the y-axis.

These figures identify that:

- the potential of a compound to elicit a target organ effect (potency) varies widely in different species;
- MTBE has low potency for all toxic actions following acute or chronic inhalation exposures, with the exception neurological effects; and
- a number of other gasoline constituents and emission products are extremely potent and produce serious, long-term adverse health impacts at very low concentrations.

Policies designed to be protective of public health characteristically consider the potential for irreversible health effects; outcomes such as severe damage to the central nervous system and cancer have historically been priority endpoints. For this analysis, the potential cancer risk associated with exposure to low concentrations of MTBE and benzene, via inhalation or ingestion, were compared. To date, expert panels reviewing the results of available studies have considered the data insufficient to classify MTBE as a human carcinogen. However, MTBE has been shown to produce cancer in laboratory animals. In this report MTBE has been considered a carcinogen. Although this issue has been debated within the scientific community, given the uncertainties it is appropriate and the practice of public health agencies in the Northeast States, to conservatively assess cancer as a potential impact. As discussed later in the text, the methods used to derive the health-protective threshold concentration for benzene and MTBE in this analysis are indicative of the scientific certainty of carcinogenicity for each compound.

Figure 1.
Comparison of Acute* Inhalation Exposure Effects
for Various Gasoline Constituents.



* Acute Exposure: Exposure to a compound for ≤ 14 days.
(m) = Mouse
(r) = Rat

LOAEL: Lowest Observable Adverse Effect Level

▲ Humans
● Animals

NOAEL: No observed Adverse Effect Level

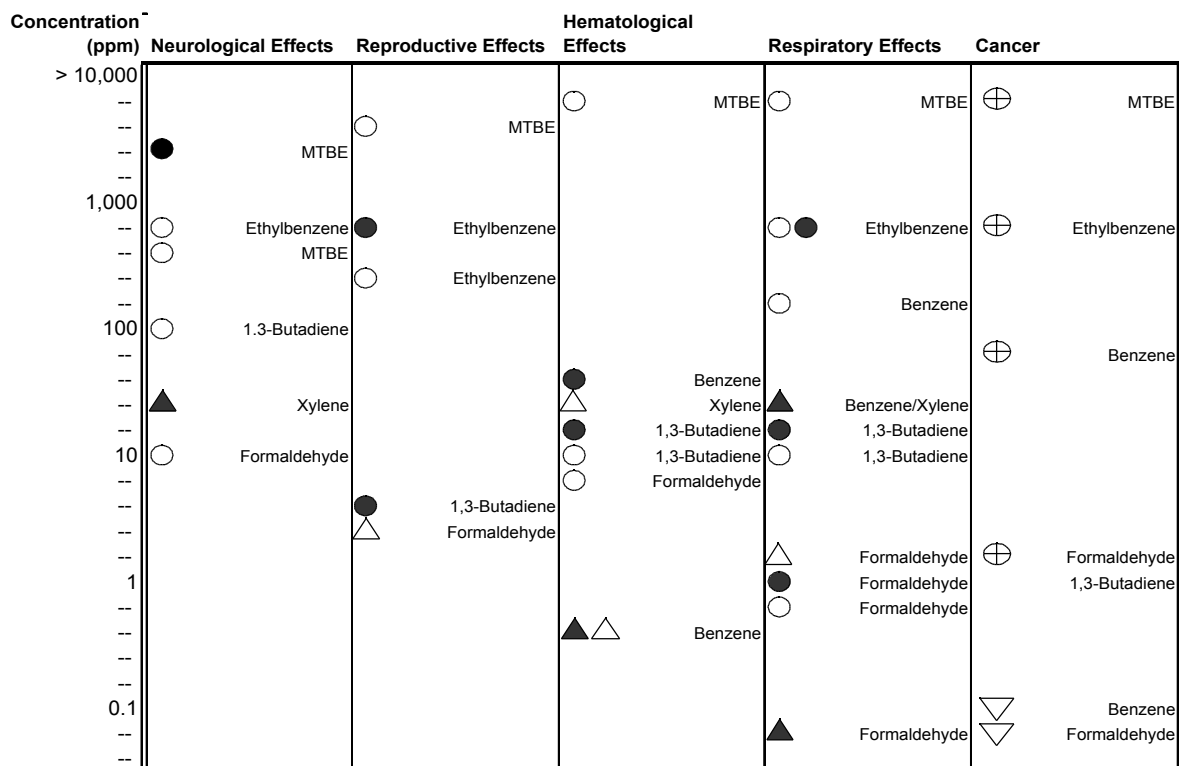
△ Humans
○ Animals

LC50: Lethal Concentration, 50%. That concentration of a compound in water or air that results in death for 50% of an exposed animal population.

Reference: Toxicological Profiles for listed compounds. U.S. DHHS, Agency for Toxic Substances and Disease Registry.

For all endpoints, the lowest published exposure concentrations resulting in observed outcome is shown.

Figure 2.
Comparison of Chronic* Inhalation Exposure Effects
for Various Gasoline Constituents.



* Chronic Exposure: Exposure to a compound for ≥ 365 days.

LOAEL: Lowest Observable Adverse Effect Level

▲ Humans
 ● Animals

⊕ Cancer Effect Level (animals)
 ▽ Cancer Effect Level (humans)

NOAEL: No observed Adverse Effect Level

△ Humans
 ○ Animals

Reference: Toxicological Profiles for listed compounds. U.S. DHHS, Agency for Toxic Substances and Disease Registry.

For all endpoints, the lowest published exposure concentrations resulting in observed outcome is shown.

B. Ambient air quality and concentrations of gasoline-related pollutants in the Northeast

Motor vehicles are the largest aggregate source of air pollution in the Northeast. As a sector, gasoline powered vehicles emit about one-third of smog-forming VOCs and NO_x in the region. Vehicles are also the primary source of carbon monoxide. Cleaner-burning gasoline is an effective strategy for reducing emissions that contribute to smog, carbon monoxide, fine particulate matter, haze, acid deposition, and toxic problems in the region. Two attributes make cleaner-burning gasoline a particularly important and effective approach to air pollution control. First, the program benefits accrue immediately upon introduction of the fuel; as opposed to new vehicle standards where the full benefits are not achieved until significant fleet turnover has occurred (about 12 years for a 90% turnover). Second, the benefits – while different in magnitude - apply to all vehicles, regardless of age and technology.

As described previously, the RFG program was designed to reduce ambient levels of ozone, a powerful respiratory irritant that adversely affects the health and well being of large segments of the population including children, the elderly and individuals engaged in outdoor activities. Ozone smog remains a persistent summertime problem in the New England states. As shown in Table IV, exceedances of the 8-hour and 1-hour ozone standards have been recorded in all six New England states during the summer of 1999. Existing data in California suggest that the RFG program has contributed to a 10-12% reduction in levels of smog where it has been used (CARB, 1998). Clean fuel programs, like RFG, are critical ozone reduction strategies for the Northeast.

Table IV.
NESCAUM Region Ozone Exceedance Day Summary for 1999
(Preliminary data through August 20, 1999)

State	Number of 8-hr Exceedance Days	Number of 1-hr Exceedance Days
Connecticut	31	11
Maine	9	1
Massachusetts	19	4
New Hampshire	8	1
New Jersey	40	10
New York	31	11
Rhode Island	11	3
Vermont	2	0
NESCAUM totals	151	41

In addition to its importance to ozone reduction programs, RFG has played an important role in reducing ambient HAP concentrations. Air quality monitoring data demonstrate that Phase 1 of the RFG program has significantly contributed to reduced ambient levels of HAPs including benzene, a known human carcinogen (Sonoma Technologies Inc, 1998). As shown in Table V, which summarizes the emission benefits of federal RFG compared to 1990 conventional gasoline, gasoline refiners have significantly exceeded the minimum statutory toxic reduction requirements of Phase 1 of the RFG program. Analyses conducted by the Northeast states and others suggest that benzene is a primary source of public health risk from exposure to vehicular emissions. The RFG program imposes a 1 percent by volume cap on benzene; most refiners are using considerably less than the allowable level (on average about 0.6 %). The use of oxygenates, such as MTBE and ethanol, contributes to reductions in air toxic emissions from motor vehicles through dilution and replacement of toxic gasoline constituents that are high in octane. Several lines of evidence strongly suggest that an increase in MTBE content results in a corresponding decrease in levels of aromatics, a major source of benzene emissions in motor vehicles. On average, benzene concentrations have decreased by approximately 43 percent in most areas where RFG is used. Ambient levels of 1,3-butadiene and acetaldehyde have also decreased in these areas. The use of RFG with MTBE has, however, resulted in increased airborne emissions of MTBE and formaldehyde.

Table V.
Emissions Reductions from Federal RFG in the Northeast States

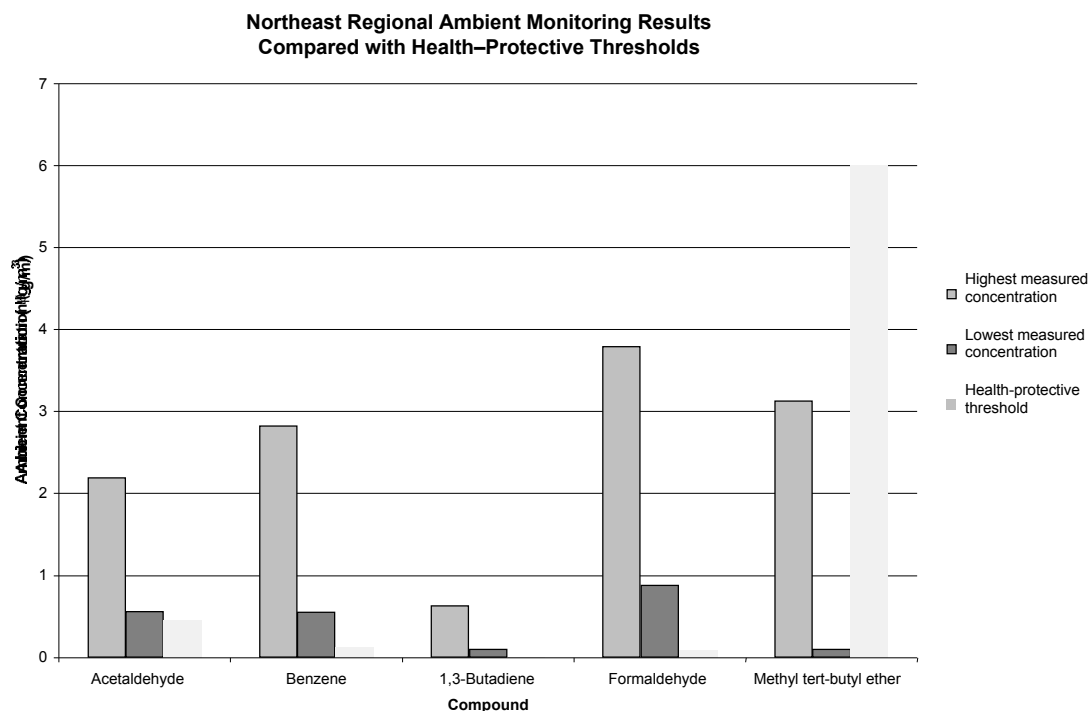
Pollutants	Phase I RFG (1995 – 1999)		Phase II RFG (2000+)
	<i>Performance Standards</i>	<i>Actual Emission Reductions (1998 average)</i>	<i>Performance Standards</i>
VOCs	17.1%	21%	27.4%
NOx	1.5%	5%	6.8%
Toxics (mass emissions)	16.5%	35%	21.5%

C. Air Quality Challenges in the Northeast

A recent review of computer dispersion model predictions from the air quality assessment portion of the EPA's Cumulative Exposure Project (CEP) (Woodruff *et al*, Caldwell *et al*) and available ambient air toxics monitoring results throughout the Northeast, identified a list of HAPs, which are present in concentrations exceeding public health protective thresholds across the region. The results of the CEP suggest that about half of the public health risk from exposure to HAPs is associated with automobile emissions. Figure 3 compares measured annual average ambient concentrations of several motor vehicle-related air HAPs in the Northeast with established health protective guidelines. Monitoring data represent the highest measured ambient concentration and the lowest measured ambient concentration for each compound in the Northeast region¹³. The health-protective standards are representative indicators of the exposure concentrations believed to be protective against carcinogenic effects (Caldwell *et al.*, 1998). These data show that even the lowest measured outdoor concentration of acetaldehyde, benzene, 1,3-butadiene and formaldehyde in the Northeast region-- the pollutants regulated under the RFG program -- exceed the established cancer standards. Whereas, the highest measured levels of MTBE in the air are about one-half the cancer standard.

¹³ Quality assured ambient monitoring results provided to NESCAUM by respective Northeast States Air Quality Agencies. These data are collected in accordance with USEPA ambient monitoring requirements.

Figure 3.



In Table VI, the emission source categories of 1990 Northeast regional average emissions of acetaldehyde, benzene, 1,3-butadiene, and formaldehyde are shown. This table was developed using the Northeast states' emissions inventory compiled for the 1990 CEP analysis¹⁴. Given the dominant contribution of mobile sources to the emissions of these pollutants of concern it is clear that emission reductions in this source sector are important elements to an air quality improvement program in the Northeast.

**Table VI.
Toxic Air Pollutants of Concern in the Northeast Region**

	Mobile	Area	Point	Total:
Acetaldehyde	61.62%	35.42%	2.96%	100.00%
Benzene	70.60%	27.61%	1.79%	100.00%
1,3-butadiene*	65.44%	24.75%	0.46%	90.65%
Formaldehyde	67.97%	29.87%	2.17%	100.00%

* Additional 9.35% of emissions attributed to secondary formation

¹⁴ Unpublished data provided by USEPA, Office of Policy. Final emissions inventory used for Cumulative Exposure Project, Assessment of Population Exposure Nationwide computer dispersion modeling, provided 1998.

IV. Overview of MTBE Health Effects:

A. General Effects

In a recent review of the potential health effects of MTBE and other oxygenates it was observed that MTBE is a moderately toxic compound, which produces adverse neurological effects in some sensitive humans (HEI, 1996). MTBE is considered a weak carcinogen in laboratory animals, it has been associated with short-term, reversible central nervous system effects, in addition MTBE has a disagreeable odor and taste in both air and water. Except for cancer, these adverse health effects may occur at environmentally relevant concentrations in sensitive members of the population. At much higher concentrations, MTBE has been shown to elicit systemic toxicity in different organ systems (kidney, liver, and endocrine) and adverse reproductive and developmental effects have also been observed (USEPA, 1997).

Anecdotal evidence suggests that some members of the population can not only detect MTBE in air or water at extremely low concentrations, but that these “sensitive” members of the population experience extreme, reversible respiratory irritation and neurological effects (NSTC, 1996). However, Northeast state experience has suggested that taste and odor characteristics of MTBE are not detectable in the general population until concentrations are well above 100 µg/L. Research studies conducted to date failed to demonstrate a statistically significant correlation between exposure to MTBE and these reported adverse health effects (Cain, 1996; Prah, 1994, and Johanson, 1995). There is a study underway at this time, evaluating the response of “self-reporting” sensitive members of the population to MTBE, via inhalation. It is anticipated that the results of this well-controlled study will be available within the next few months and may provide scientific evidence to confirm or refute a correlation between MTBE exposure and these adverse neurological effects.

The reviews suggest that the MTBE exposures to the general population (via ingestion or inhalation) are low and believed to be without adverse short or long-term adverse health effects. The reviews underscore however, that MTBE contaminates drinking water and will substantially increase the exposure for a subset of individuals in the population. MTBE contamination of groundwater directly impacts the concentration of MTBE in the residential air as it evaporates during general potable water use, cooking, and bathing and showering.

Odor and taste responses are not classed as toxic actions of MTBE by all health agencies. However, many agencies consider taste and odor as a nuisance and are adopting secondary drinking water standards or guidelines that are designed to avoid “undesirable” water quality (USEPA, 1997). MTBE’s odor and taste detection limits may be considered beneficial in preventing exposures to drinking water concentrations above health-protective thresholds. However, the variability in the human odor and taste detection threshold for MTBE suggests that the level of protection afforded may be minimal. If evidence in the Northeast states’ public health departments is validated, the benefit of secondary standards for MTBE may be limited as the primary drinking water

standards appear to be lower than the taste and odor detection thresholds for the majority of the population.

B. Cancer

MTBE has been shown to produce cancer in both male rats and male and female mice following long-term inhalation exposures (Bird *et al*, 1997). Belpoggi and colleagues demonstrated an increased incidence of certain cancer types following oral gavage (Belpoggi *et al*, 1995; Belpoggi *et al*, 1998). These analyses included very high concentration exposures for the laboratory animals; therefore, the relevance to human exposures and health risk remain unclear. At this time, the USEPA has not officially issued a cancer classification based on review of these analyses. However, based on a previous review, the USEPA had identified MTBE as a Group C carcinogen (possibly carcinogenic to humans). The International Agency for Research on Cancer, the National Toxicology Program and the State of California have all recently determined that there is insufficient evidence to classify MTBE as a carcinogenic substance for humans. In each of these recent determinations a substantial body of scientific opinion dissented with these determinations.

The results of NESCAUM's relative risk comparison for MTBE in ambient air suggested that when added to RFG, MTBE displaces more potent carcinogenic materials, thus producing a lower cancer potential in the mixture and in tailpipe emissions from vehicles. This analysis demonstrated that, if MTBE were a carcinogen, it was 7 times less potent than benzene and 25 times less potent than 1,3-butadiene (NESCAUM, 1998).

C. Short-term, reversible effects

Some people report experiencing short-term, reversible effects from exposure to RFG, containing MTBE. The adverse health effect reported by these individuals include: headaches, dizziness, irritation of the eyes, burning sensation of the nose and throat, nausea or vomiting, a sensation of "spaciness" or disorientation and cough. (HEI, 1996; IAOF, 1997). Patients receiving high doses of MTBE for dissolution of gall stones have exhibited clinical signs of CNS depression, mild liver abnormalities, dizziness and headache. Some motorists have reported similar subjective symptoms. Chamber studies with volunteers exposed up to 50 parts per million (ppm) in air MTBE did not report the health effects described above (Cain, W.S. *et al* 1996). Variability in human sensitivity as well as exposure variables may explain the laboratory findings. In Alaska, the reports of such acute effects were coincident with the introduction of MTBE in RFG and media coverage (Cain, W.S. *et al* 1996). The responses were not observed after substitution of ethanol for MTBE or removal of RFG from the market. Efforts to assess whether similar responses were observed in the other states did not support the adverse health effect assertions in the Alaskan population. However, there have been anecdotal claims of similar adverse health effects in individuals exposed to RFG containing MTBE. Two epidemiological studies have linked responses observed in small populations to adverse health effects, but have been unable to link the responses to MTBE (IAOF, 1997; NRC, 1996).

Given the substantially higher concentrations of MTBE in RFG, it is possible that the combined acute effects of other gasoline components are greater with RFG than with conventional gasoline. Further, the discernible odor for some members of the population associated with ether-based oxygenates may increase sensitivity to the odor of other constituents in gasoline. These factors may cause a larger group of sensitive individuals to notice the acute effects of gasoline exhaust than in the past. The reports of acute health effects tend to be concentrated in specific locations and the incidence of complaints has diminished significantly since the early stages of the RFG program. Some researchers postulate that the odor detection of MTBE in air and water would diminish with repeated or long-term exposures, which may also explain the decline in the incidence of repeated complaints. Further analyses, particularly in self-reporting sensitive members of the population, are necessary to clarify the adverse acute health effects caused by MTBE exposure.

D. Other effects of MTBE

Reproductive and developmental effects have been observed in animal studies. These adverse effects were associated with extremely high exposures in rats, mice, and rabbits (approximately 1000 to 10,000 times environmentally relevant exposure levels) (USEPA, 1997). Therefore, although MTBE can produce developmental and reproductive injury, the response appears to be limited to high dose exposures, which also produce maternal toxicity.

A recent analysis postulated an endocrine or immunologic response to MTBE that adversely impacted reproductive fertility in animals. However, these effects were in response to high dose exposures, which are unlikely to be seen at environmental concentrations of MTBE (Williams *et al*, 1999).

Renal toxicity has been well demonstrated following sub-chronic exposures to MTBE in laboratory animals. However, this effect is also a high dose response in the animal studies that would not occur in the general population exposed to environmentally relevant concentrations. This response may be related to a direct action of MTBE but also possibly due the metabolites of MTBE, tert-butyl alcohol (TBA) and formaldehyde, both of which are toxic to the kidney at moderately high doses (HEI, 1996).

MTBE and other oxygenates reduce the carbon monoxide emissions, thereby reducing the adverse health impact of carbon monoxide on sensitive individuals, such as those with heart conditions and breathing difficulties. Although data presented earlier in this paper support the VOC, NO_x, and HAP emission reductions associated with the RFG program, it is not known whether the degree of reduction in carbon monoxide emissions results in a substantial reduction in overall exposures to carbon monoxide.

Population-based surveys and epidemiologic studies have suggested an association between MTBE exposure and asthma incidence in the general population. Due to variability in the responses of individuals exposed to MTBE it is difficult to confirm this suggestive evidence. MTBE, like ozone, is a respiratory irritant, which has been

proposed as a plausible mechanism for potential asthmatic effects of MTBE. More research is necessary to evaluate this potential effect.

A recent California report reviews epidemiologic evidence of elevated asthma rates in children who live near highways or heavily traveled streets. This study proposes that the metabolites and atmospheric degradation products of fuels and MTBE might be linked to airway hyper-reactivity and the asthma response (IAOF, 1997)

V. Toxic Effects of MTBE substitutes:

A. Oxygenates

Much of the scientific evidence assessing the toxicity of fuel oxygenates was recently compiled in a comprehensive Health Effects Institute Analysis (HEI, 1996). Available alternative oxygenates include: ethanol, tert-butyl alcohol (TBA), ethyl tert-butyl ether (ETBE), tert-amyl methyl ether (TAME), and diisopropyl ether (DIPE).

Scientific evaluation of other ethers has been limited and conclusions regarding the potential short and long-term effects are difficult to make in the absence of peer-reviewed information. However, for the scientific analyses conducted to date:

- evaluated ethers have been shown to have similar systemic toxicity in animal studies, including: increased adrenal gland, liver, and kidney weights, and neurological effects;
- MTBE has been shown to be more potent than other ethers;
- very limited scientific evidence exists regarding the potential cancer effects of other oxygenates although structure activity analyses of these ethers suggest that ETBE, TAME, and MTBE would be carcinogenic in rodent (HEI, 1996);
- the odor and taste detection thresholds for ETBE, MTBE, and TAME are all very low and the physical characteristics of all ethers quite similar. These data suggest that the groundwater impacts will likely be important considerations for other ethers as well;

Ethanol as a special case oxygenate

HEI in the published review of oxygenates made the following concluding remarks regarding ethanol:

- ethanol has been shown to be associated with increased rates of certain tumors of the digestive track when other carcinogens are present. These findings all involve oral exposures of moderate levels of alcohol and there is no known data of such a link to inhalation exposures; and
- ethanol added to gasoline may increase the volatility of other components, resulting in increasing evaporative emissions of VOCs, including benzene.

Available refinery modeling predicts that ethanol is the most likely gasoline additive to replace MTBE, even if the oxygenate mandate is removed. However, several significant air quality issues need to be addressed before the Northeast states pursue policies that result in increased use of ethanol. Combustion of ethanol-blended gasoline results in substantial (50 to 70%) increases of acetaldehyde emissions. Ambient air levels of acetaldehyde are presently far in excess of health-based risk standards in a number of areas in the Northeast.

Refineries are likely to use ethanol at 10% by volume in conventional gasoline to take advantage of the statutory one pound Reid Vapor Pressure waiver, which would lead to a substantial increase in VOC emissions. Unless all gasoline sold in the region contains ethanol, the blending or commingling of ethanol with non-ethanol gasoline blends in vehicle gas tanks will result in a significant increase in VOC emissions due to increased fuel volatility. Many of these VOC are known or suspected carcinogens and concerns regarding increased emissions of these compounds through ethanol use are valid.

Replacement of MTBE in RFG with ethanol at levels of up to 10 % in gasoline would produce a widespread increase in population exposures to low levels of ethanol and ethanol breakdown products in the ambient air. Ethanol, much like MTBE, is a relatively low potency compound that produces atmospheric breakdown products of concern (acetaldehyde for ethanol and formaldehyde for MTBE). Both compounds also cause adverse neurological effects as described in this summary. Unlike MTBE, ethanol itself has been well studied, particularly when considering ingestion of this compound. It is appropriate to assess the impacts, not only of ethanol emissions on public health and environmental quality, but also the impact of ethanol on atmospheric breakdown products and concurrent VOC emission increases associated with ethanol blending in RFG.

The adverse health effects associated with short-term inhalation or ingestion exposures to relatively high concentrations of ethanol are primarily adverse effects on the central nervous system (Middaugh et al, 1992; Moore et al, 1993; Weiss and Laties, 1964 Weiss and Laties, 1989; HEI, 1996). Although neurological effects are observed following exposure to both MTBE and ethanol, in a recent review of the scientific literature exposure to ethanol, as would be expected, has not been demonstrated to result in the adverse acute neurological effects reported for MTBE in exposed populations (HEI, 1996). Scientific information exists regarding adverse reproductive and developmental effects of ethanol in exposed animal and human populations (HEI, 1996, Middaugh and Gentry, 1992). These analyses demonstrate that exposure to ethanol during pregnancy results in brain damage for the exposed fetus.

In humans, long term exposures to elevated concentrations of ethanol have been shown to result in a number of adverse effects on organ systems including: liver abnormalities (Carithers, 1992), damage to the tissue of the heart (Cotran *et al*, 1994), and adverse effects on the neurological system similar to those effects observed following short term exposures. Ethanol exposure has also been associated with cancers in the liver, esophagus, oral cavity, pharynx and larynx (NAS/NRC, 1982; IARC, 1988).

Anticipated health effects or potential exposures from inhalation of low levels of ethanol and ethanol by products should not be inferred from the high dose studies in humans or animals. As discussed above, high dose studies demonstrate neurological, developmental, systemic and carcinogenic actions after high level oral or inhalation exposures. These studies also identify blood ethanol levels at which the actions occur. However, direct extrapolation through comparison of blood levels is complicated by a potential non-linearity of the low dose kinetics based on different metabolic and physiologic clearance mechanisms in certain sub-populations (Pastino *et al.* 1997).

Generally reviews of the literature have concluded that ethanol inhalation from RFG has little public health significance. The highest inhalation exposure occurs during refueling, levels of 1 to 49 ppm have been determined (HEI 1996). Inhalation studies in rats found 10 μ M concentrations of ethanol in the blood after 6-hour exposures to 50 ppm in air. Modeling estimated that blood levels of 25 μ M would be produced in male adult humans after 50 ppm exposure for 6 hours (Pastino *et al.* 1997). 50 ppm appears to be the most severe exposure anticipated with the use of RFG containing ethanol. The corresponding blood ethanol level increase under this exposure scenario would be 1.1 mg/L, given the endogenous levels of 1.5 mg/L reported in unexposed individuals, this would result in a total blood ethanol content of 2.6 mg/L.

The lowest demonstrated blood level peak associated with a concurrent adverse health effect is the demonstrated threshold for reproductive injury in a human fetus at a maternal blood ethanol level of 350 mg/L (Streissguth *et al.* 1981, 1994, Jacobson and Jacobson 1995). These data would suggest a greater than two orders of magnitude safety factor between the worst case exposure in humans from inhalation of ambient ethanol with RFG use and the lowest threshold for a toxic effect in humans. The concentration of ethanol and metabolic breakdown products of ethanol, like acetaldehyde, is determined by the magnitude of exposure and the metabolic processing of the exposed individual. Metabolism of compounds like ethanol is known to vary between population groups, ages, and genders. A more careful characterization of the distribution of risk(s) across the general population would be helpful to determine whether a sensitive sub population may be a greater risk for adverse effects of ethanol.

In summary, important elements to consider when assessing the affect of increased ethanol concentrations in the gasoline supply would include: 1) the variability in metabolism and potential toxicity of ethanol in the general population; 2) the increased endogenous production of acetaldehyde during ethanol metabolism; 3) the exposure risks presented by increased evaporative emissions of benzene and other VOCs from gasoline; and 4) the potential increase in the ambient levels of the respiratory toxins such as acetaldehyde and peroxyacyl nitrate (PAN).

B. Other gasoline additives

TBA is a metabolite of MTBE. This compound is also a potential oxygenate for use in gasoline. Animal studies have demonstrated an increase in mineralization of the kidneys in rats and evidence of carcinogenicity in different organ systems of rats and mice (Cirvello *et al.*, 1995; NTP, 1994). There is little data available to assess the potential

carcinogenic effect of TBA in humans. However, based on the animal data available, TBA's toxicity (potency) is greater than MTBE.

Alkylate and Aromatics

There are two likely non-oxygenate alternatives to MTBE: aromatics and alkylates. Aromatics is a term for a group of gasoline constituents including benzene, toluene and xylene. These compounds are produced by the reformer unit at refineries and are a relatively high in octane. The use of aromatics to replace MTBE will substantially increase toxic emissions from motor vehicles using RFG and conventional gasoline (CG). As illustrated throughout this technical paper, in the Northeast, ambient levels of several aromatic mobile source toxics including benzene, far exceed health-based risk standards.

Alkylate, a generic term for C₅-C₁₀ isoparaffins, provide octane without apparent increases in toxic emissions, and may not pose a risk to water resources. However, due to these attractive features, alkylate is already in short supply. Alkylate is formed when isobutane is alkylated with C₃ to C₅ olefins. Most alkylate mixtures consist of C₅-C₈ isoparaffins but C₉+ isoparaffins often account for as much as 10-20% of the mixture according to Albright and Eckert (1999). The precise composition of alkylate to be blended in fuels will vary according to the refinery process. Therefore, conclusions relative to the toxicology of this class of compounds in air or water must be considered cautiously and be narrowly constrained to the specific mixture. It is possible to group similarly structured compounds by "families" and to perform a risk characterization. However, without more information regarding the composition and percentage of each family in a given fuel product, it is not possible to complete this assessment at this time.

A limited number of peer-reviewed scientific studies investigating the adverse effects of alkylate mixtures were identified during this analysis. These studies evaluated only certain fractions of the alkylate stream, the light alkylate naphtha distillates, and are not sufficiently robust to evaluate the effects of widespread environmental and human exposures. Although these studies focused on the light alkylate naphtha elements of the refinery stream, the results demonstrated that some alkylate mixtures were nephrotoxic and neurotoxic following chronic exposure. These studies did not find indication of carcinogenic, reproductive, or developmental actions (Schreiner *et al.* 1998). The authors proposed that kidney physiology unique to the male rats is the basis for the nephrotoxicity and that it would not be present in humans. In a separate analysis, light alkylate naphtha was shown to have no adverse systemic, reproductive, or developmental effects in rats following inhalation exposures (Bui *et al.*, 1998). These analyses compared slightly different light alkylate naphtha streams. Schreiner *et al.* used a higher C₈-C₉ fraction than Bui *et al.*, who focused their research on the C₄-C₆ fraction primarily.

Both the Schreiner and Bui studies provide helpful insight into the potential toxicity of some alkylate mixtures. Adverse effects on the central nervous system, kidney and behavioral effects are the primary actions identified. These effects were observed with the longer carbon chain light alkylate naphtha mixtures and occurred only following high dose exposures. The evaluation of carcinogenic effects is complicated and incomplete at this time.

There are important limitations in the peer-reviewed scientific evaluation of “alkylate” toxicity. It appears at this time that only a portion of the potential products have been studied and the analyses have been limited to rat exposure assessment. Further investigation of the mixtures is needed, particularly with consideration of the potential exposures to the general population and the apparent mixture-specific toxicity profiles. Future research efforts should include, but not be limited to, pharmacokinetic uptake and distribution after both oral and inhalation exposures.

VI. Testing of fuel products and additives

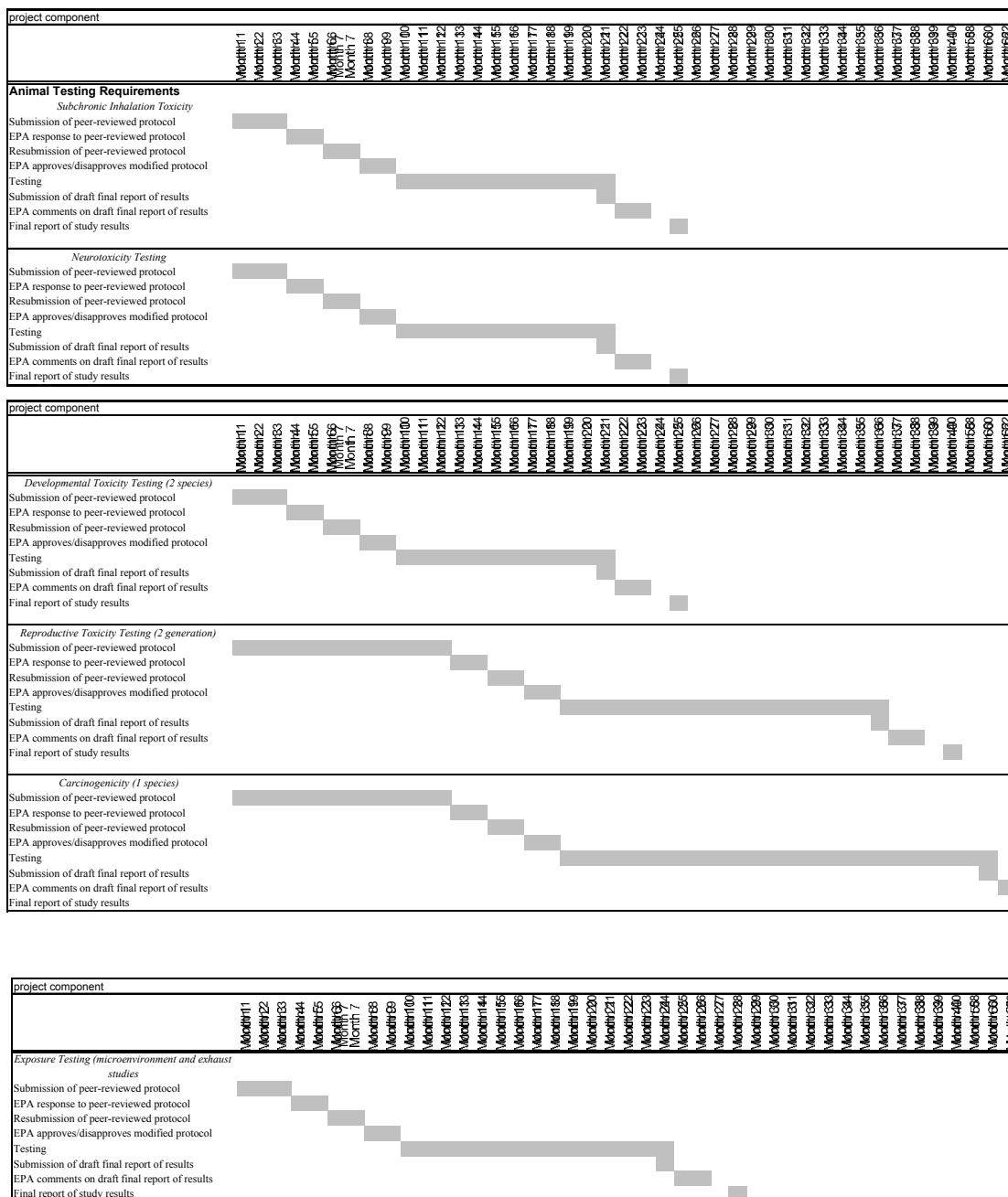
Should changes to the RFG program result in the decision to substantially increase the use of a gasoline constituent or additive, a rigorous multi-media assessment must be undertaken to proactively assess potential public health and environmental impacts. Specifically, research is needed on the health effects and environmental behavior of likely MTBE substitutes including ethanol, alkylate and various aromatic compounds. It is important to look both at these constituents alone and as part of the gasoline mixture. It is also important to assess changed evaporative and combustion by product emissions the alteration to the fuel mixture.

The unanticipated degree of adverse impacts of MTBE on water resources provides a powerful example of the need to study the potential impacts of new gasoline products on air, water, and soil, as well as the need to understand the effect of dramatically increasing any current constituents of gasoline. Changes to the RFG program will by design or necessity result in substantial increases in the use of existing gasoline constituents or the introduction of new additives.

The CAA, Section 211(b) established a registration process for fuels and additives, which includes testing requirements for adverse health effects associated with these fuels and additives (Standard and Alternative Tier II testing requirements). The existing toxicity testing requirements established under this section of the CAA must be streamlined to enable more timely assessment of potentially adverse health impacts of gasoline constituents. As shown in Figure 4, the current timeline afforded for the evaluation of baseline gasoline and oxygenated gasoline under the Alternative Tier II requirements of section 211(b) include as much as 18 months of “protocol development and review.” Unless clearly necessary, readily available and accepted protocols to assess the apparently routine toxicity endpoint established under the Alternative Tier II testing requirements should be used. The abbreviation of the protocol development requirements alone will substantially shorten the duration of testing various fuel constituents.

Figure 4. 211(b) Alternative Testing Requirements¹⁵

211(b) Alternative Tier II- Health Effect Testing Schedules*



The pending fuel reformulation demand development of a more responsive and timely testing regime for evaporative and combustion by-products. Without a more expeditious evaluation methodology, states will be faced with fuel shortages or, as has historically

¹⁵ As identified in Attachment E to August 27, 1998 USEPA correspondence to Dr. Carol Henry, American Petroleum Institute.

been the case, with the use of inadequately understood compounds in literally millions of combustion sources.

VII. Multi-Media Exposure to MTBE and Other Gasoline Constituents

The adverse health effect endpoints and relative potencies for many components of conventional and RFG are shown in Tables II and III and Figures 1-3. As noted previously in this text, gasoline is a mixture of compounds that can elicit short-term, reversible effects and long-term irreversible effects. By far the most potent carcinogenic compounds found in gasoline evaporative or combustion emissions are 1,3-butadiene, benzene, and formaldehyde. The potential public health risk(s) associated with any of these compounds will be associated with the exposure and concentration. This paper will present an initial multi-media analysis of exposure and subsequent risk associated with MTBE and benzene for comparative risk purposes. Benzene is compared with MTBE because: 1) benzene emissions (both evaporative and emission) have been reduced with RFG; 2) benzene is a compound known to be found in drinking water associated with fuel leaks or spills; and 3) an extensive data set of ambient and exposure concentrations is available in the peer-reviewed literature for benzene.

A. Health-protective thresholds

The public health agencies of the Northeast states use available scientific evidence to develop health-protective thresholds for compounds in multiple environmental media. These health-protective thresholds are not absolute indicators of anticipated adverse health impact following exposure, but rather represent exposure concentrations that are expected to result in no adverse health effects with long-term exposure. Thresholds like those shown in this technical paper are used by air quality and public health professionals for screening environmental contaminants of potential concern, for targeting additional emission reduction efforts, and for identifying areas requiring more refined assessment of potential health impact. The thresholds used for risk comparisons in the technical paper are protective of potential cancer effects and are therefore regarded as conservative indications of potential risk. However, it is important to note that these thresholds, due to uncertainties and insufficient scientific evidence needed to quantify effects, may not adequately account for the potential acute respiratory and/or neurological to sensitive members of the population following exposure to compounds like formaldehyde, acetaldehyde, and MTBE.

B. Threshold determination for initial comparative exposure assessment

There are different methodologies used to develop health-protective thresholds with available scientific evidence. When considering cancer effects, one can use a high-to-low dose linear extrapolation method. Using this methodology, the high dose in animals that resulted in an observed tumor is extrapolated to a low dose, which is expected to not result in tumor formation following exposure. This methodology is commonly used to

establish a 10^{-6} lifetime risk upper bound estimate for compounds when considering a 70 year exposure. However, for MTBE, in addition to the uncertainty regarding the potential carcinogenicity in humans, there have been no published scientific evaluations of the cancer potential of MTBE when consumed voluntarily in drinking water. Some public health agencies in the Northeast have determined that the uncertainty associated with the extrapolation of animal study results reported by Belpoggi and Bird to human risk are substantial enough to prevent the use of a high-to-low dose linear extrapolation methodology for MTBE. In this case, safety factors are used to adjust the concentration shown to result in a no adverse non-cancer effects (NOAEL) in exposed animals to a predictive allowable health protective threshold for lifetime exposure in humans. It is common practice when considering animal carcinogens in this methodology, for an additional uncertainty factor to be applied to account for potential carcinogenic effects in humans.

For this analysis, the uncertainty factor approach was used to derive a health-protective threshold for MTBE. In animal studies, researchers observed a low-dose adverse kidney (renal) effect in female rats (Robinson et al, 1990; Klan et al, 1992). Using these studies, a NOAEL of 1000 mg/kg/day was derived. For the exposure analysis the NOAEL of 1000 mg/kg/day was divided by an uncertainty factor of 10,000 to derive a daily health-protective threshold dose of 0.1 mg/kg/day for humans. The uncertainty adjustment accounts for: 1) chronic rather than sub-chronic exposure, 2) human rather than animal exposure, 3) inter-individual variability in exposed humans, and 4) potential carcinogenic effects in humans. This methodology, for an average 70 kg human, develops a daily health protective exposure dose of 700 µg/day. The approach of using an additional 10X safety factor to account for potential carcinogenicity is often used by the USEPA, Office of Drinking Water when regulating Group C carcinogens (USEPA, 1989).

For benzene, a known human carcinogen, the wealth of scientific study supports the use of the conservative high-to-low dose linear extrapolation method to derive a health-protective threshold for a daily human exposure. The approach would result in a health-protective threshold for benzene (indicative of a 10^{-6} risk concentration) of 1 µg/L. This concentration is often used as an action limit by state public health agencies to conduct a more refined assessment of risk. The USEPA has established a maximum contaminant level (MCL) for benzene in drinking water of 5 µg/L. An MCL is the enforceable standard used in the regulation of public drinking water systems. If one were to use the health-protective threshold concentration of 1 microgram/liter, assuming an average ingestion rate of 2 liters/day, this health-protective threshold would result in a daily exposure allowance of 2 µg/day.

C. NESCAUM's comparative exposure analysis

In order to understand the differences in exposure and the consequences of exposure on health risk(s), different exposure scenarios were compared in this initial comparative exposure assessment. This exposure analysis is intended to compare the highest and lowest potential exposure to MTBE and benzene in different daily activity patterns, using available, peer-reviewed personal exposure monitoring results from the scientific literature. This analysis is intended to provide an estimate of the potential upper and lower potential limit of exposure. More refined exposure analysis would be possible using personal activity diaries and Northeast state-specific personal exposure monitoring. A more comprehensive distributional exposure assessment would provide a more complete understanding of the frequency of exposure under the "high" or "low" exposure scenarios and a more detailed understanding of the percentage of the general population at all risk levels in between. A distributional analyses is beyond the scope of this technical paper at this time however, and would require data not currently available to NESCAUM.

Human Contact with MTBE:

Human contact with MTBE and other gasoline constituents has been reported from environmental contamination and/or workplace exposures (Brown, 1997; Wallace, 1996; Huber, 1995). Inhalation exposures to vapors have been shown to span a wide range. The highest ambient concentrations have been observed in workers who handle MTBE and gasoline products, the general public during refueling, and in individuals homes when contaminated groundwater is used for cooking, showering and bathing (Brown, 1997; Keller, 1998). Oral and dermal exposures to MTBE and other gasoline-related compounds can also occur from drinking, cooking, and bathing and showering with water contaminated with these compounds. For this analysis, ingestion and inhalation were considered the key exposure routes as dermal absorption of MTBE has been demonstrated to be very low and without significant impact on potential important systemic exposure. (Johnson, 1993; Huber, 1993).

Analysis of Exposures:

The "high" and "low" exposure scenarios in this analysis are shown to illustrate the various elements of exposure important for health risk. Tables VII and VIII illustrate the personal exposure concentrations of MTBE and benzene measured by others (Huber, 1993; Brown, 1997; Hartle, 1993; and Wallace, 1996). Figures 5, 6, and 7 indicate the relative importance of the inhalation and ingestion exposure to the various concentrations of MTBE and benzene measured during the daily activities shown in the tables. These figures compare exposure estimates for individuals with and without MTBE- and benzene-contaminated drinking water (concentrations above state drinking water standards). High and low estimates are provided to represent the highest and lowest reported average air concentrations of MTBE measured outdoor and within a private residence, as shown in the "exposure bound" column in each table. Therefore, the high/low values within each water contamination level category represent the maximum

and minimum inhalation exposures, based on available exposure monitoring results. The use of these values is intended to provide an upper and lower estimate of the inhalation contribution to total daily exposure given the variability reported in the published literature.

In order to qualitatively represent the magnitude of potential daily individual exposures, the air and water concentrations of MTBE and benzene were considered. The daily dose was calculated for a 70 kg adult, with an inhalation rate of 0.0139 m³/min, who is consuming 2 liters of water per day. Water contamination concentrations were considered to be 35 µg/L or 100 µg/L for MTBE and 5 µg/L for benzene.

As shown in Figures 5, 6, and 7 inhalation of MTBE and benzene are the key exposure pathways. Figures 5 and 6 compare the “no Stage II” scenario for MTBE and benzene. This scenario establishes an initial high exposure assumption, given the volatilization of gasoline during refueling. Figure 5, illustrates that, with residential drinking water contamination at 35 µg/L, using the lowest measured airborne concentrations of MTBE during various daily activities, the daily health protective threshold is not exceeded. If however, one incorporates the high exposure assumption (an attached garage increasing the residential air concentrations of MTBE and an “outdoors” ambient air concentration of 36 µg/m³--approximately 10X the highest measured concentration in the Northeast) the health protective threshold is exceeded. As shown in Figure 6, non-residential ambient air exposure to benzene is substantial enough to exceed the daily threshold exposure concentration. Incorporation of measured residential exposure concentrations of benzene, with no drinking water contamination, would essentially double this exposure estimate.

Stage II vapor recovery was shown to reduce daily exposures to MTBE by approximately 50% through a reduction in high exposure concentrations during refueling (Huber, 1993). Figure 7 illustrates the reduced exposure to MTBE expected with use of Stage II vapor recovery at the refueling pumps. Under this scenario, the daily health protective threshold would not be exceeded with a drinking water concentration of 35 µg/L, even under the high exposure assumptions discussed above. However, a drinking water concentration of 100 µg/L would contribute to a daily health protective threshold exceedance under high or low exposure assumptions. Stage II vapor recovery did not significantly reduce exposure to benzene during refueling in three regions studied by Hartle (Hartle, 1993). Wallace did not evaluate the effectiveness of this emission control technology (Wallace, 1996). Therefore, a Stage II exposure scenario is not shown for benzene. Since 1993 vapor recovery system design and performance has been substantially improved. Recent Northeast state experience suggests that Stage II vapor recovery systems are greater than 90% effective at capturing MTBE and benzene vapors during refueling. These systems would therefore be expected to reduce exposure beyond that shown in this initial exposure assessment.

Table VII.
Microenvironmental Exposures to Methyl Tertiary Butyl Ether

Type of Exposure	MTBE Concentration mg/m ³	Duration min/event	Exposure Frequency	Inhalation Rate m ³ /min	Exposure µg/day	"Exposure Bound"
Refueling <i>Stage II</i>	13	2 (2x/week)	Daily	0.0139	102.99	Low Estimate
In gas station <i>Stage II</i>	1.59	3 (2x/week)	Daily	0.0139	19.67	Low Estimate
Refueling <i>No Stage II</i>	36	2 (2x/week)	Daily	0.0139	285.23	High Estimate
In gas station <i>No Stage II</i>	3.6	3 (2x/week)	Daily	0.0139	44.54	High Estimate
Commuting	0.061	90	Daily	0.0139	76.31	-
Residential	0.018	660	Daily	0.0139	165.13	-
Outdoors	0.036	205	Daily	0.0139	102.58	High Estimate
	0.0036	205	Daily	0.0139	10.26	Low Estimate

Measured MTBE exposure concentrations reported by Huber, 1993 and Brown, 1997.

Table VIII.
Microenvironmental Exposure to Benzene

Type of Exposure	Benzene Concentration mg/m ³	Duration min/ event	Exposure Frequency	Inhalation Rate m ³ /min	Exposure µg/day	"Exposure Bound"
Commute/in vehicle	0.006	90	daily	0.0139	7.506	Low
	0.04	90	daily	0.0139	50.04	High
Residence, non-smoker	0.002	660	daily	0.0139	18.348	Low
	0.008	660	daily	0.0139	73.392	High
Outdoors	0.019	205	daily	0.0139	54.1405	High
	0.002	205	daily	0.0139	5.699	Low
					0	
Refueling	0.85	0.57	daily (2 min x 2x/week)	0.0139	6.73455	No Stage II

Benzene concentrations reported by Hartle, 1993 and Wallace, 1996.

Figure 5. Estimated Daily Exposure to MTBE, No Stage II
(Estimated for the High Ambient Exposure and the Low Ambient Exposure)

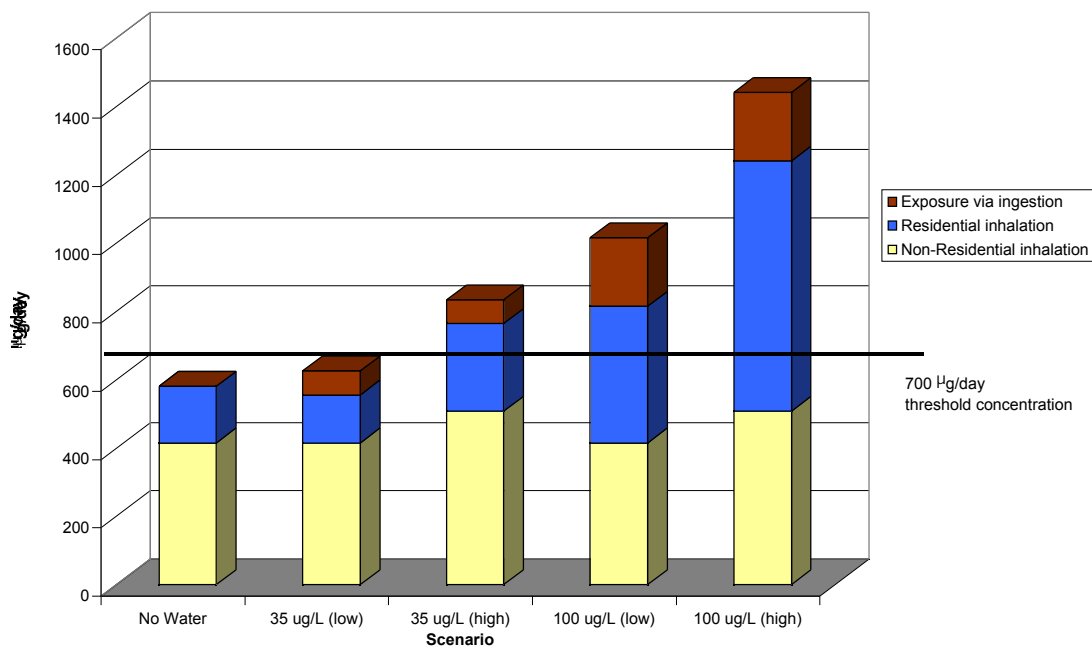


Figure 6. Estimated Daily Exposure to Benzene, No Stage II
(Estimated for the High Ambient Exposure and the Low Ambient Exposure)

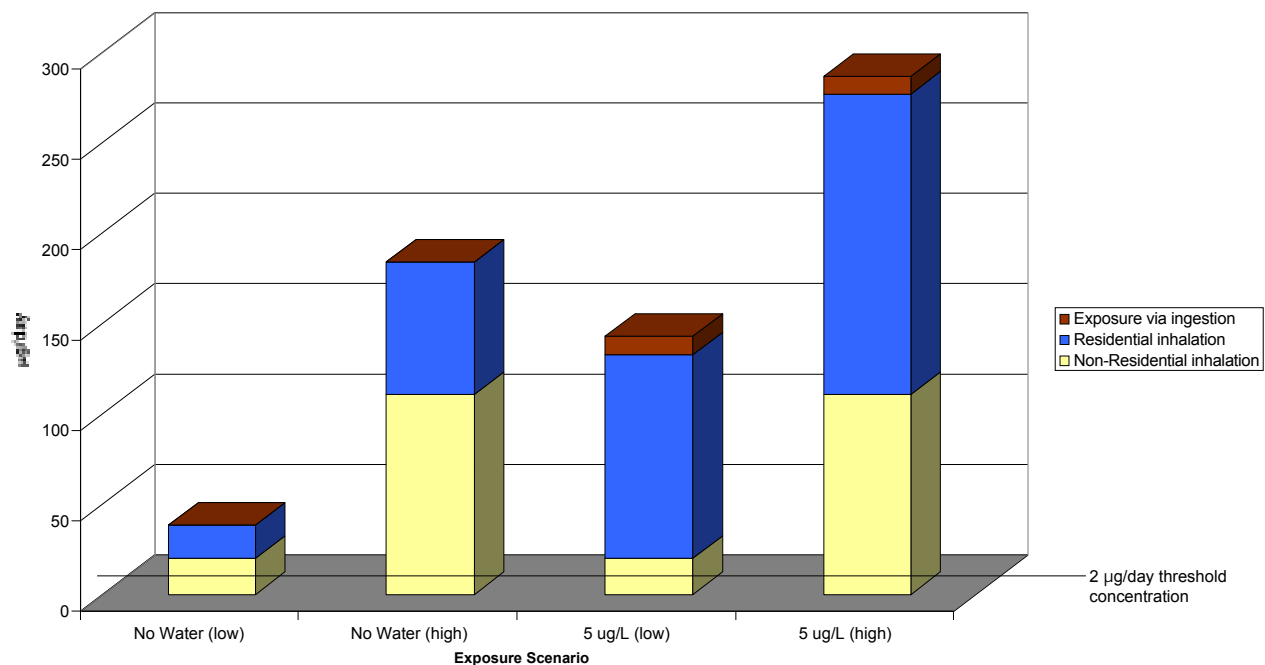
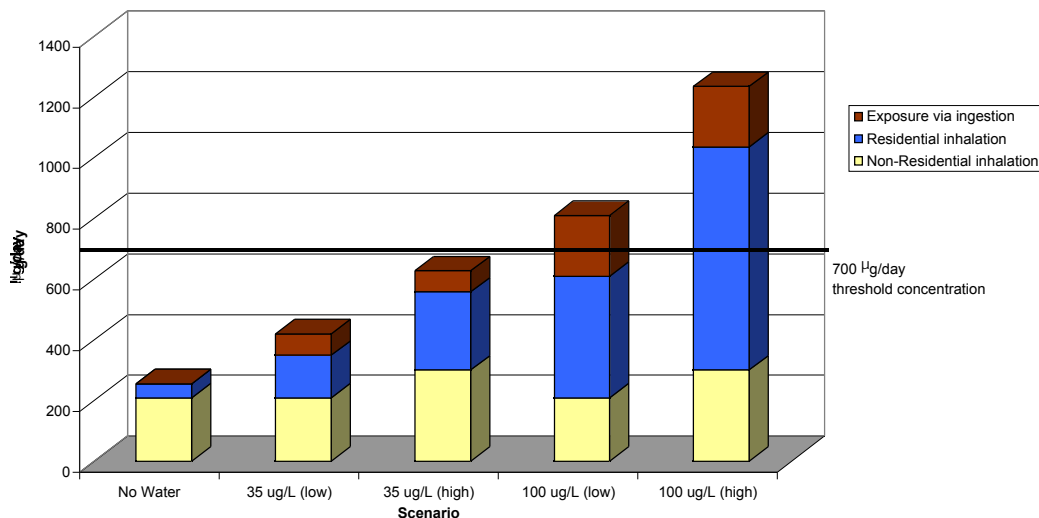


Figure 7. Estimated Daily Exposure to MTBE, With Stage II
(Estimated for the High Ambient Exposure and the Low Ambient Exposure)



VIII.Important Data Limitations

At this time, there are a number of data limitations, which if corrected would lead to a more complete comparative toxicity assessment. These limitations must be recognized to avoid a policy decision that would reduce efforts to provide public health protection when considering evaporative and combustion emissions from gasoline.

1. Very little data exists regarding environmental fate, transport, and potency of substitutes to MTBE.
2. Limited data exist regarding the effect of reformulating fuels without MTBE on evaporative or combustion by products.
3. At this time no published scientific studies are available, which have evaluated the carcinogenic potential of MTBE when *consumed* in drinking water.
4. Limited data exist regarding the environmental fate, transport, and temporal persistence of MTBE contamination in drinking water supplies.
5. Available measurements of environmental exposures to some gasoline-related products in both air and water are adequate to support a qualitative, comparative assessment of the potential health hazard. They do not support a distributional analysis of variability in exposure across the Northeast general population. A distributional analysis would require more exposure monitoring data than available to NESCAUM at this time. This type of analysis would provide a more refined assessment of the percentage of the population at different risk levels; therefore, a clearer representation of the magnitude of potential health risks.
6. Absence of ethanol and aldehyde exposure data from regions using ethanol in RFG.

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Northeast States for Coordinated Air Use Management

Attachment II

**MTBE in Ground and Surface Waters
of the NESCAUM Region**

August 1999

Table of Contents

- I. Pathways of MTBE into ground and surface waters.
 - A. Point sources (e.g. gasoline releases from underground storage systems, pipelines)
 - B. Non-point sources (e.g. air deposition, stormwater run-off, small spills)
 - C. Above-ground versus below-ground gasoline releases
- II. Characteristics of MTBE in ground and surface waters relative to other gasoline constituents.
 - A. Coincidence of MTBE and BTEX compounds
 - B. Mobility of MTBE and other oxygenates/BTEX compounds in groundwater
 - C. Persistence/biodegradability of MTBE, other oxygenates, and BTEX
 - D. Comparison of MTBE detections in areas requiring reformulated gasoline (RFG) and areas not requiring RFG
- III. General synopsis of measured MTBE levels in NESCAUM region.
 - A. Susceptibility of groundwater sources in the NESCAUM region to contamination
 - B. Ambient monitoring
 - C. Measured MTBE levels in ground and surface waters
 - i. Regional studies
 - ii. State-specific information from NESCAUM region
- IV. Summary

MTBE in Ground and Surface Waters of the NESCAUM Region

August 1999

I. Pathways of MTBE into ground and surface waters.

The distribution, storage, and use of oxygenated gasoline are the major sources of methyl-*tert*-butyl ether (MTBE) in the environment.¹ Releases into the environment can occur through point and nonpoint sources. Examples of point sources are underground storage tanks, pipelines, and refueling facilities. Nonpoint sources include stormwater run-off from surface spills, and deposition from the air during rainfall.

A. Point sources of MTBE

Petroleum storage tank systems are the largest group of potential point sources for MTBE contamination in the environment. Contamination from these sources is not necessarily always due to leaks from the storage tank itself, but may be associated with gasoline releases from system piping, dispensers, or tank overfills. For gasoline releases associated with underground storage systems, the amount of MTBE reaching the groundwater table can be quite high. For example, MTBE concentrations in local groundwater reached 200,000 micrograms per liter ($\mu\text{g/L}$) at one underground gasoline release site.² In general, when monitors detect such high levels of MTBE, other gasoline constituents such as benzene, toluene, ethylbenzene, and xylenes (collectively called “BTEX”) also occur within the area.

In 1988, over 2 million underground gasoline storage systems existed at over 700,000 facilities in the United States. An EPA program requiring underground storage systems to meet more stringent release prevention and detection standards by December 1998 caused many of these underground systems to be replaced or removed. EPA now estimates there are about 1.2 million underground storage systems at 415,000 facilities, of which about 195,000 are service stations. The other 220,000 facilities comprise a range of entities including, but not limited to, marinas, airports, hospitals, small businesses, local government facilities, and agricultural facilities. EPA statistics identified slightly over 300,000 gasoline release sites nationwide needing corrective action, with cleanup completed at 130,000 of the sites.³

¹ National Science and Technology Council, 1997, Interagency Assessment of Oxygenated Fuels: Washington, DC, Committee on Environment and Natural Resources, Chapter 2.

² National Science and Technology Council, 1997, p. 2-6. One microgram per liter is approximately equivalent to one part per billion (ppb).

³ National Science and Technology Council, 1997, p. 2-6.

No reliable estimates exist of past or current annual MTBE or other oxygenate releases from underground storage systems due to the difficulty in determining release rates, durations, and the use of oxygenates in the released gasoline. EPA expects the improved physical condition of newer underground storage systems, better leak detection monitoring, and the reduced population of underground tanks to reduce considerably the amount of MTBE and other gasoline components released into the environment. Whether a significant reduction in gasoline contamination occurs will depend upon the extent of compliance with the EPA program, particularly by the non-service station facility owners who may be less familiar with EPA's requirements. Furthermore, not all point source gasoline releases are directly from leaking storage tanks, but are associated with tank overfills and other gasoline handling activities at the facilities. Spillage associated with gasoline handling can occur even where state-of-the-art tanks and leak detection systems are used.

In addition to large releases from gasoline storage systems, some groundwater well testing indicates that small surface gasoline spills can also contribute MTBE to groundwater. The extent and persistence of contamination, however, are typically less than from much larger releases from underground storage systems. Spills on the order of a few tens of gallons or less from singular events such as ruptured automobile gasoline tanks caused by traffic accidents can lead to groundwater MTBE contamination in excess of 100 µg/L and contaminate a number of wells within a local area. The State of Maine documented three such incidents of MTBE contamination in water wells due to small surface gasoline spills, which are described below.

- In December 1997, a car accident in the town of Standish, ME, spilled 8 to 10 gallons of gasoline that contaminated 24 area wells with MTBE. Eleven wells were contaminated above the State's 35 µg/L (ppb) state drinking water standard for MTBE. Two of the wells were contaminated at levels of MTBE exceeding 1,000 µg/L, with the highest level reaching 6,500 µg/L in the well nearest the accident site. When the State discovered the contaminated wells in May 1998, it located and removed 79 cubic yards of contaminated soil. The contamination extended to the top of the underlying bedrock at a depth of nine feet below the surface. The degree of soil contamination at the bedrock surface was 100 to 230 µg/L of gasoline (total hydrocarbons).
- At another small surface gasoline spill site in the town of Whitefield, ME, a bedrock well for a local elementary school was contaminated to a level of 900 µg/L MTBE. The State estimated the spill was 20 gallons of gasoline or less, and traced the source of the spill to a nearby area about 120 feet from the well where cars were parked on the grass. Toluene and ethylbenzene were found in the soil at the spill site, but no BTEX was detected in a monitoring well 200 feet away from the spill.
- In the town of Windham, ME, two public water supply wells 900 to 1100 feet from underground gasoline tanks were contaminated to levels of 1 to 6 µg/L MTBE. The tanks were state-of-the-art technology, double-walled and only 10 months old when the MTBE contamination was discovered. Extensive testing showed that the tanks

did not leak directly to the ground, nor were any vapor leaks found after extensive testing. The only plausible cause of the contamination was from gasoline overfills that penetrated the backfill in the tank pit. The amount spilled in this instance was estimated to be approximately 10 to 40 gallons, based on contamination levels in the tank pit backfill (benzene did not exceed more than 60 µg/L, toluene did not exceed 53 µg/L, while MTBE levels reached 7,140 µg/L). No BTEX was found in a monitoring well 350 feet away from the tank site, nor in the water supply wells 900-1100 feet away.

The episodes documented by Maine indicate that small gasoline surface spills can contaminate groundwater with MTBE, including cases in which MTBE levels exceed drinking water standards.

B. Nonpoint sources of MTBE

Where groundwater monitoring detects low levels of MTBE, the source may be a point source but could also be due to a nonpoint source such as stormwater run-off or deposition from the air.⁴ MTBE on ground surfaces from gasoline spills may dissolve into stormwater run-off that can recharge an underground aquifer or collect in a surface lake. A USGS study of stormwater in 118 drainage basins throughout the United States found that urban land surfaces, such as roadways and parking lots, are the primary nonpoint source of most VOCs, including BTEX, detected in stormwater samples.⁵ The study, however, could not rule out deposition from urban air as an important secondary nonpoint source for MTBE, unlike the other VOCs which had atmospheric concentrations too low for partitioning to rainfall to be a possible explanation for their measured groundwater concentrations.

Another USGS study analyzed atmospheric samples for a number of VOCs over an area in southern New Jersey, and found that only MTBE concentrations were high enough to potentially explain its frequent detection in shallow groundwater.⁶ MTBE enters the air through evaporation from fuel tanks and spills, and from unburned MTBE in vehicle exhaust. Weather patterns disperse MTBE in the atmosphere, and a small portion partitions into rainwater falling back to the surface. Based on the partitioning between the water and air phases, an atmospheric MTBE concentration of 1 part per billion-volume (ppbv) at 5° C could contribute 1 µg/L or less to groundwater through rainfall. Higher levels may occur near gasoline refueling sites, parking garages, or roadways where local ambient MTBE concentrations can be higher than the general background. For example, if MTBE levels in local ambient air reach 30 ppbv, then the portion partitioned into rainfall recharging the groundwater could reach 30 µg/L, particularly

⁴ Squillace, P.J., J.F. Pankow, N.E. Korte, and J.S. Zogorski, Revised 2/98, Environmental Behavior and Fate of Methyl *tert*-Butyl Ether (MTBE): U.S. Geological Survey Fact Sheet FS-203-96.

⁵ Lopes, T.J. and D.A. Bender, 1998, Nonpoint sources of volatile organic compounds in urban areas - relative importance of land surfaces and air, *Envtl. Pollution*, V. 101, pp. 221-230.

⁶ Baehr, A.L., P.E. Stackelberg, and R.J. Baker, 1999, Evaluation of the atmosphere as a source of volatile organic compounds in shallow groundwater, *Water Resources Research*, V. 35, pp. 127-136.

during the colder winter months.⁷ Atmospheric concentrations of MTBE quickly drop as distance increases from the vapor source, so the higher potential concentrations in rainfall near these locations is not representative of regional MTBE atmospheric concentrations.

Air emissions from some industrial facilities such as oil refineries also contribute to MTBE in the ambient air that may later reach ground and surface waters through precipitation. Emissions of MTBE along with the oxygenates methanol (MeOH) and *tert*-butyl alcohol (TBA) are reported to the USEPA's annual Toxics Release Inventory. Emissions of MTBE are almost entirely associated with its use as a fuel oxygenate, whereas MeOH and TBA are associated with a variety of other commercial and industrial uses. EPA's Toxics Release Inventory does not include other fuel oxygenates such as ethyl-*tert*-butyl ether (ETBE), *tert*-amyl methyl ether (TAME), di-isopropyl ether (DIPE), and ethanol (EtOH).

C. Above-ground versus below-ground gasoline releases

The separation into point and non-point sources in the preceding sections follows the description in the Interagency Assessment of Oxygenated Fuels by the National Science and Technology Council, Committee on Environment and Natural Resources (1997).⁸ While this is the traditional method for thinking about pollution sources, an alternative method for classifying sources can be in terms of how different releases pose different risks to groundwater. In this context, a distinction between above- and below-ground gasoline releases may be a more useful guide for evaluating risks.

Underground gasoline releases are generally limited to leaking tanks. There are two important features with leaking tanks. First, the amount of gas released can be large, often exceeding hundreds of gallons. Second, the release occurs in relatively close proximity to groundwater with less of an opportunity for loss to the atmosphere through volatilization. The more chemically reactive constituents may be lost through a combination of adherence to soil and microbial decomposition, but the size of the gasoline release may overwhelm these processes for a period of time after the release occurs. As a consequence, releases associated with underground tank leaks are more likely to result in groundwater contamination by a variety of gasoline constituents (e.g. MTBE, BTEX, di- and trimethyl benzenes).

Surface spills can range from a single small spill (e.g., spill while refueling a lawnmower) to moderate spills (e.g., tank overfills, car accidents) to large spills (e.g., leaking above-ground gas tank). Surface spills can also be a single isolated event (e.g., release from a car accident) or a repeated event (e.g., daily spills while refueling automobiles as a gas station). For surface spills, loss by volatilization may be important

⁷ Squillace *et al.* revised 2/98. The upper limit assumes an ambient air temperature of 5 °C. Higher temperatures will lead to lower MTBE concentrations partitioning from the air to rainwater. Therefore, MTBE used during the winter months to control carbon monoxide could be a relatively greater potential source of MTBE deposition from the air than MTBE used during the summer months to control ozone.

⁸ National Science and Technology Council, 1997, pp. 2-15/19.

(especially when spills occur on a relatively impermeable surface like pavement). Because surface spills must be carried into groundwater through soil by rainwater, adherence to soil organic matter and microbial decomposition may considerably influence what gasoline constituents reach the water table. The smaller the spill, the more important the attenuation processes can be. As a consequence, for a small surface spill (e.g., 10 gallons or less) or deposition by rainfall, MTBE may be the only gasoline constituent to reach groundwater because of its greater water solubility and resistance to microbial decomposition compared to BTEX.

II. Characteristics of MTBE in ground and surface waters relative to other gasoline constituents.

A. Coincidence of MTBE and BTEX compounds

Concurrent measurement of MTBE and BTEX from the same water sample is evidence of a possible gasoline release site nearby. In a study of the Connecticut, Housatonic and Thames River basins during 1993-1995, the United States Geological Survey (USGS) tested samples from 103 monitoring wells for 60 different volatile organic compounds (VOCs), including MTBE and the BTEX compounds.⁹ In addition, the USGS sampled 30 existing water supply wells in bedrock aquifers during the summer of 1995 within the region. The minimum reported concentration was 0.2 µg/L for all VOCs except dibromochloropropane, toluene, and xylenes (1.0 µg/L). The USGS detected 25 different VOCs out of the 60 VOCs being monitored. Of the 25 VOCs detected, MTBE was the most frequently occurring compound (25% of the wells sampled, or 33 out of the 133 wells).¹⁰

Only 12% of the wells with MTBE also had BTEX compounds (4 out of 33 wells). Thirty-one percent of the MTBE detections occurred in shallow groundwater wells with no known nearby point source. Sixty-nine percent of the MTBE detections occurred in shallow groundwater wells located within one-quarter mile of gasoline stations or other known underground gasoline storage systems. Whether these facilities are the contamination sources or simply a reflection of greater population density is not known. For example, if a nearby gasoline station is a marker of greater population density, then contamination by other gasoline handling activities, such as emptying lawnmower fuel tanks onto the ground, could be more common in the area. Therefore, the existence of a nearby gasoline station may not necessarily mean it is the most likely source of contamination if it is a coincidental indicator of greater population density with associated increased gasoline handling activities not directly connected to the gasoline station.

⁹ The combined river basins encompass most of CT, western MA, western NH, eastern VT, and small parts of NY, RI, and Canada.

¹⁰ Grady, S.J., 1997, Volatile Organic Compounds in Ground Water in the Connecticut, Housatonic, and Thames River Basins, 1993-1995: U.S. Geological Survey Fact Sheet 029-97.

Of the 30 water supply wells in the USGS study, seven had low levels of detectable MTBE, with a maximum of 2.2 µg/L. Six of the seven water supply wells with MTBE were not located within one-quarter mile of a known point source, e.g. a gasoline station. The water supply wells did not have detectable levels of benzene, ethylbenzene or xylenes, but three wells had small but detectable toluene levels, with a maximum of 1.8 µg/L. The measured levels of MTBE were less than EPA's drinking water advisory for consumer acceptability and the toluene levels were less than the maximum contaminant level.

The highest MTBE concentration found during the USGS study was 5.8 µg/L from a very shallow (5 feet in depth) urban streambed well in Connecticut. This well did not have detectable levels of BTEX compounds.

Overall, while 25% of the 133 wells had detectable amounts of MTBE, only 1.5% of the wells had detectable benzene (2 out of 133 wells), 0.7% had detectable ethylbenzene (1 well), 4.5% had detectable toluene (6 wells), and 0.7% had detectable xylenes (1 well). The maximum detected levels of benzene (73 µg/L) and xylenes (300 µg/L) occurred in urban wells and suggest nearby point sources. Interestingly, the highest MTBE level detected in this group of urban wells was only 2.4 µg/L, which may indicate a gasoline release event (or events) no longer occurring and MTBE has already migrated past the sampling wells.

Detection of BTEX is generally an indicator of gasoline contamination from a release site, but concurrent MTBE detections with BTEX in the USGS study were rare (12% of wells with detectable MTBE also had BTEX). In addition, a significant portion of shallow wells with detectable MTBE levels (31%) were not located within one-quarter mile of a known gasoline storage site, as was also the case with most of the MTBE detections in deeper water supply wells (86%). These facts coupled with the generally low concentrations of MTBE observed throughout the study area (from 0.2 to 5.8 µg/L) suggest that a significant number of the MTBE detections cannot be attributed to nearby gasoline storage system releases.¹¹

USGS scientists reported similar results for the frequency of concurrent detections of MTBE and BTEX compounds in at least three additional studies. The first was a study of 210 shallow urban groundwater wells and springs in eight urban areas.¹² Of the total sampling sites, 61 wells and one spring had detectable MTBE or BTEX concentrations above the minimum reporting level of 0.2 µg/L. Of those sites with detectable MTBE or BTEX levels, 79% had MTBE only, 13% had MTBE and BTEX, and 8% had BTEX only. MTBE was the second most frequently detected VOC (27% of the 210 urban wells and springs tested). Chloroform was the most frequently detected VOC (28%).

¹¹ Grady, 1997.

¹² Squillace, P.J., J.S. Zogorski, W.G. Wilber, and C.V. Price, 1996, Preliminary Assessment of the Occurrence and Possible Sources of MTBE in Groundwater in the United States, 1993-1994; *Envtl. Sci. & Tech.*, V. 30, pp. 1721-1730. The eight urban areas were Denver, CO, New England, Dallas/Fort Worth, TX, Reno, NV, Albany, NY, Las Vegas, NV, Atlanta, GA, and Albuquerque, NM.

In a study of 20 urban wells in the Great Valley of Pennsylvania (Lower Susquehanna River Basin), the USGS found MTBE in 10 of the 20 wells (0.06 µg/L detection limit), while benzene (0.06 µg/L detection limit), toluene (0.05 µg/L detection limit), ethylbenzene (0.08 µg/L detection limit) and xylenes (0.13 µg/L detection limit) were detected in only two wells each. MTBE was the second most commonly detected VOC in the 20 urban wells, with chloroform found in 13 wells (0.06 µg/L detection limit).¹³

In a third study, the USGS collected samples from a network of 72 wells in the Kirkwood-Cohansey aquifer system of southern New Jersey.¹⁴ The USGS detected MTBE in 44.4% of the wells (non-detection value <0.1 µg/L), making it the second most common VOC detected in the aquifer system behind chloroform (80.5%, non-detection value <0.05 µg/L). The median of detected MTBE concentration was 0.20 µg/L, with a maximum of 43.8 µg/L. Several pesticides were also frequently detected, with atrazine the most common (50.0%, non-detection value <0.001 µg/L). In contrast, the BTEX compounds were relatively rare, with toluene detected in 6.9% of the wells, ethylbenzene in 4.2%, and xylenes in 4.2% (non-detection values <0.05 µg/L).

Consistent with the USGS studies, a recent study by the State of Maine also found low detection frequencies of the BTEX compounds with MTBE in Maine water supplies. The Maine results are described below in the section on state-specific MTBE information from the NESCAUM region.

While the relatively high frequency of MTBE-only detections in groundwater may indicate non-point sources such as storm water run-off, some MTBE-only detections can signal the leading edge of a gasoline release from a point source such as an underground storage tank. At a site in South Carolina where almost 6,000 gallons of gasoline escaped from an underground tank in 1991, a monitoring well detected MTBE about 120 meters downgradient from the release site in advance of the BTEX plume.¹⁵ Between 1994 and 1997, MTBE levels at the well increased to over 40,000 µg/L. The monitoring well, however, did not detect BTEX compounds until January 1997.

The coincidence of MTBE and BTEX may also be a function of the local hydrogeologic setting. A study of 609 leaking petroleum storage tanks in Texas found that in 50 to 60 percent of test wells, co-occurrence of MTBE and benzene remained steady over a period of seven years.¹⁶ This implied to the researchers that the MTBE plumes were not

¹³ Daly, M.H. and B.D. Lindsey, 1996, Occurrence and Concentrations of Volatile Organic Compounds in Shallow Ground Water in the Lower Susquehanna River Basin, Pennsylvania and Maryland: U.S. Geological Survey Water-Resources Investigation Report 96-4141 (Table 3).

¹⁴ Stackelberg, P.E., J.A. Hopple, and L.J. Kauffman, 1997, Occurrence of nitrate, pesticides, and volatile organic compounds in the Kirkwood-Cohansey aquifer system, southern New Jersey, U.S. Geological Survey Water-Resources Investigations Report 97-4241.

¹⁵ Buxton, H.T., J.E. Landmeyer, A.L. Baehr, C.D. Church, and P.G. Tratnyek, in press 1998, Interdisciplinary Investigation of Subsurface Contaminant Transport and Fate at Point-Source Releases of Gasoline Containing MTBE; Petroleum Hydrocarbon Conference (Houston, TX), November 11-14, 1997.

¹⁶ Mace, R.E. and W.-J. Choi, 1998, The Size and Behavior of MTBE Plumes in Texas; Proceedings of the 1998 Petroleum Hydrocarbons and Organic Chemicals in Ground Water: Prevention, Detection, and Remediation (Houston, TX), November 11-13, 1998, pp. 1-11.

increasing in length relative to benzene plumes, at least at the regional level. The MTBE plumes were, on average, about 27 feet longer than the benzene plumes at equivalent concentrations of 10 parts per billion. The researchers found that most MTBE plumes in their study appeared to be stable and similar in size to benzene plumes.

The researchers in the Texas plume study contrasted their findings to results from a California study that found MTBE plumes at 29 sites in San Diego County were still growing relative to benzene plumes. In the California study, the coincidence of MTBE and BTEX compounds detected at individual wells decreased over a three-year period.¹⁷ Assuming the BTEX plumes were stable, the California results suggested that the MTBE plumes were mobile relative to BTEX. A possible difference between the results of the two studies is the local hydrogeologic setting. The majority of Texas plumes are in clay-rich sediments, while a significant majority of the California sites are in alluvial deposits,¹⁸ which could allow for greater MTBE dispersion relative to BTEX.

There are a number of factors that complicate conclusions on the coincidence of MTBE with BTEX compounds in large gasoline plumes.¹⁹ First, the “release dates” for MTBE and benzene may not be the same if the site was previously contaminated by a gasoline release prior to the use of significant MTBE levels in gasoline. Second, the study time period may not be sufficiently long to determine whether the MTBE plumes are in fact stable or transient relative to the benzene plumes. Third, studies of MTBE and benzene plume relationships based on specific concentrations (typically regulatory action levels for MTBE and benzene) may give different results if different concentrations are used. Future studies of large gasoline releases will help resolve these areas of uncertainty.

In addition to large gasoline releases, smaller spills of only a few gallons can potentially contaminate a number of wells with MTBE at distances of 1600 feet or more from the spillage site, although BTEX may be absent. As mentioned in the point source section above, one example of this occurred after an automobile accident in Standish, Maine in December 1997. As a result of the accident, approximately 8 to 10 gallons of gasoline spilled on the ground. In May of the following year, a nearby private well user notified state health officials of possible well contamination. Initial testing found 6,500 µg/L of MTBE in the fractured bedrock well, decreasing ten-fold to 680 µg/L at another well 400 feet downgradient. The wells did not contain any detectable amounts of BTEX. In contrast, soil samples several hundred feet from the highly contaminated well site contained a full range of gasoline constituents. Subsequent sampling since the initial well tests revealed 24 wells with some level of detectable MTBE, while detectable BTEX remained absent. Of the 24 contaminated wells, 11 wells reached MTBE concentrations above Maine’s 25 µg/L action level. Currently, the most distant contaminated well (peaking at 3 µg/L) is about 1600 feet away from the initial well site. Based on current

¹⁷ Happel, A.M., E.H. Beckenbach, and R.U. Halden, 1998, An Evaluation of MTBE Impacts to California Groundwater Resources, Lawrence Livermore National Laboratory, UCRL-AR-130897, Chap. 5.

¹⁸ Mace and Choi, 1998, *supra* note 14.

¹⁹ Happel, *et al.*, 1998, *supra* note 15.

decreasing MTBE concentration trends, Maine officials expect all the wells to be below the State's 35 µg/L drinking water standard in two to three years.²⁰

In general, when groundwater contains MTBE levels above 10 µg/L, the contamination source could be a point source such as an underground storage system release, especially when BTEX is detected, either concurrently or at some later time. MTBE levels below about 2 µg/L without concurrent BTEX contamination may be due to nonpoint sources such as stormwater run-off. A distant point source, however, cannot always be ruled out because the MTBE could be the leading edge of a larger gasoline plume, or part of a residual gasoline spill in which BTEX has largely been attenuated through biodegradation. In addition, gasoline spills of only a few gallons may also contaminate groundwater with MTBE without detection of BTEX compounds. MTBE concentrations can be significant from these smaller spills, peaking well over 1000 µg/L, but are relatively transient compared to larger gasoline releases.

MTBE and BTEX can occur simultaneously at relatively low concentrations in surface waters where the use of gasoline-powered watercraft is common. A USGS study of several lakes in Sussex County, New Jersey co-detected MTBE and BTEX compounds on at least one sampling day during the summer of 1998.²¹ On June 24, concentrations of MTBE in Cranberry Lake ranged from 1.6 to 15.0 µg/L, decreasing with depth. For the sampling site with the highest MTBE level, concentrations of benzene, toluene, ethylbenzene, and xylenes were 0.18, 1.2, 0.18, and 0.97 µg/L, respectively. Measurements in Cranberry Lake later on September 8 indicated MTBE concentrations were as high as 29 µg/L and uniform with lake depth due to increased vertical mixing. While MTBE increased, all BTEX compounds decreased to less than 0.20 µg/L. September 9 sampling in Lake Lackawanna, a second Sussex County lake where the use of gasoline-powered watercraft is prevalent, found similar results as the September 8 sampling in Cranberry Lake.

Based on the lake size and MTBE concentrations, the USGS estimated 52 gallons of gasoline containing 10% MTBE by volume were in Cranberry Lake on June 24, and 95 gallons were in the lake on September 8. In addition to MTBE, sampling also detected the fuel oxygenate TAME in Cranberry Lake. The TAME concentrations ranged from 0.07 µg/L to 0.43 µg/L on June 24 and from 0.20 to 0.69 µg/L on September 8. The increase in MTBE and TAME concentrations later in the summer with the concurrent decrease in BTEX over the same time period is in part due to the greater volatilization and degradation rates of BTEX compounds relative to the fuel oxygenates.²²

No MTBE, TAME, BTEX, or other VOC compounds were detected during September sampling in two nearby lakes where motorized watercraft use is prohibited. One lake,

²⁰ Oral communication from Bruce Hunter, Maine Department of Environmental Protection, April 14, 1999.

²¹ Baehr, A.L. and O.S. Zapecza, 1998, Methyl Tert-Butyl Ether (MTBE) and Other Volatile Organic Compounds in Lakes in Byram Township, Sussex County, New Jersey, Summer 1998: U.S. Geological Survey Water-Resources Investigations Report 98-4264.

²² Baehr & Zapecza, 1998.

Forest Lake, is surrounded by a densely populated community, but prohibits gasoline-powered watercraft. The second lake, Stag Pond, is privately owned and in a sparsely populated area.

The New Jersey study indicates that the presence of fuel oxygenates and BTEX in surface waters could be a source of VOC contamination for the underlying aquifer.²³ This will be a cause of concern for communities that rely on drinking water from aquifers connected to surface waters where the use of gasoline-powered watercraft is common.

The co-presence of BTEX compounds with decreasing concentrations later in the summer, stratification of MTBE concentrations with depth during early summer, and greater vertical mixing with higher MTBE concentrations later in the summer appear to be typical of lakes where gasoline-powered watercraft are common.²⁴ The time at which complete vertical mixing occurs can differ by lake, however, with a 1997 study at Donner Lake, California, indicating complete vertical mixing had not occurred by November 18. The study also found little inter-annual persistence of MTBE, with the major loss occurring apparently by MTBE volatilization to the air from the lake surface.²⁵

B. Mobility of MTBE and other oxygenates/BTEX compounds in groundwater

MTBE readily dissolves in water and moves through the groundwater table at a similar rate as the groundwater itself. BTEX compounds, on the other hand, have a somewhat greater tendency to attach to soils in the aquifer, hence slowing their mobility through the aquifer relative to the groundwater. The different mobility of MTBE relative to BTEX compounds is one factor contributing to MTBE plumes in groundwater spreading over a greater area in an underground aquifer than BTEX plumes from the same gasoline release site.²⁶ In addition, MTBE generally advances ahead of BTEX compounds. As a result, monitoring wells located downgradient from a gasoline release site often detect MTBE before the arrival of BTEX compounds. For large gasoline releases, MTBE may be the only VOC detected initially, with its concentration rising before detecting BTEX compounds later, as observed at the South Carolina gasoline release site described in the above section.

The other ether oxygenates are also fairly soluble in water. Therefore, ether oxygenates such as ETBE, TAME, and DIPE, if used to replace MTBE, are also likely to travel in the groundwater table ahead of BTEX compounds.²⁷ MTBE, however, is two to five times

²³ Baehr & Zapecza, 1998.

²⁴ See Health & Environmental Assessment of MTBE: Report to the Governor and Legislature of the State of California as Sponsored by SB 521, Vols. I & IV (November 1998). See also Boughton, C.J. and M.S. Lico, 1998, Volatile organic compounds in Lake Tahoe, Nevada and California, July-September 1997: U.S. Geological Survey Fact Sheet FS-055-98.

²⁵ Reuter, J.E., B.C. Allen, R.C. Richards, J.F. Pankow, C.R. Goldman, R.L. Scholl, and J.S. Seyfried, 1998, Concentrations, Sources, and Fate of the Gasoline Oxygenate Methyl *tert*-Butyl Ether (MTBE) in a Multiple-Use Lake, *Envtl. Sci. & Technol.*, V. 32, pp. 3666-3672.

²⁶ Squillace, *et al.*, 1996, *supra* note 11, p. 1727.

²⁷ Squillace, *et al.*, revised 2/98, *supra* note 7, p. 5.

more soluble in water than the other ether oxygenates,²⁸ so concentrations of the other ethers, if used in similar volumes in gasoline, are likely to be less than MTBE for equivalently sized gasoline releases. The alcohols MeOH, EtOH and TBA are completely soluble in water,²⁹ so their concentrations can be much larger in groundwater compared to the ether oxygenates immediately after a gasoline release event.

The greater solvency of the alcohols MeOH and EtOH in water has given rise to concerns about co-solvency effects with BTEX in groundwater. If an oxygenate acts as a “co-solvent” for BTEX, then it may enhance the mobility of BTEX compounds through groundwater relative to a gasoline release with no oxygenates present. Research generally indicates that co-solvent effects do not occur until ether oxygenate concentrations in groundwater reach about 1% (10,000 mg/L) or more by volume.³⁰ Gasoline containing MTBE at 15% by volume results in no more than 0.75% (7,500 mg/L) by volume when equilibrated with water. The greater solubility of the alcohols, however, may have a co-solvency impact on BTEX in groundwater. While a gasoline:water ratio of 1:10 (v/v) of up to 85% MeOH in gasoline showed no co-solvency effect, higher gasoline:water ratios did demonstrate a MeOH co-solvency effect on BTEX. Greater BTEX solvency occurred when aqueous MeOH reached concentrations of 8% by volume. As the aqueous MeOH concentration increased up to 50%, the aqueous BTEX concentrations also increased.³¹

No co-solvency effect was found for a 1:10 (v/v) ratio of gasoline to water for gasoline containing 10% EtOH by volume.³² Higher gasoline:water ratios may demonstrate a co-solvency effect as has been seen with MeOH, but, as the United States Geological Survey has noted, there appears to be little information in terms of field studies that characterize the influence of EtOH on BTEX plumes.³³ In Brazil, where most of the gasoline sold is a mixture of 78% gasoline and 22% EtOH (recently changed to 24% EtOH), researchers have looked at EtOH co-solvency effects under laboratory conditions. When the aqueous EtOH fraction increased from 0.93% to 15.8%, the solubility of benzene, toluene, and xylenes increased 67%, 89% and 90%, respectively.³⁴

In addition to their solubility, the degree to which fuel oxygenates spread in groundwater also depends in part on their biodegradability (see below) and the physical characteristics of the groundwater aquifer. The spread of dissolved fuel oxygenates in groundwater will vary between aquifers due to differences in permeability, porosity, and hydraulic

²⁸ National Science and Technology Council, 1997, *supra* note 1, p. 2-51 (Table 2.14).

²⁹ National Science and Technology Council, 1997, *supra* note 1, p. 2-51 (Table 2.14).

³⁰ National Science and Technology Council, 1997, *supra* note 1, p. 2-53, and *references therein*.

³¹ National Science and Technology Council, 1997, *supra* note 1, p. 2-54, and *references therein*; Poulsen, M., L. Lemon, and J.F. Barker, 1992, Dissolution of Monoaromatic Hydrocarbons into Groundwater from Gasoline-Oxygenate Mixtures, *Environ. Sci. & Technol.*, V. 26, pp. 2483-2489.

³² National Science and Technology Council, 1997, *supra* note 1, p. 2-53/54, and *references therein*.

³³ U.S. Geological Survey, Peer Review Comments on “Health and Environmental Assessment of MTBE,” submitted to Peter M. Rooney, Secretary, California Environmental Protection Agency, December 23, 1998 (located at <http://www.calepa.ca.gov/programs/mtbe/comments.htm>).

³⁴ Corseuil, H.X. and M. Fernandes, 1999, Co-Solvency Effect in Aquifers Contaminated with Ethanol-Amended Gasoline, in *Natural Attenuation of Chlorinated Solvents, Petroleum Hydrocarbons, and Other Organic Compounds*, ed. B.C. Alleman and A. Leeson, Battelle Press.

gradients. Speeds can vary from a few millimeters per year to a meter per day, and be even larger near a pumping well due to an increased hydraulic gradient.³⁵ As mentioned in the preceding section, results from plume studies in Texas suggest fairly stable MTBE and benzene plumes in clay-rich sediments, whereas studies from sites in California suggest MTBE may be more mobile in alluvial deposits. The Texas plume studies also found that gasoline plumes in unconsolidated fine-grain sand were on average larger than plumes in clay-rich sediments.³⁶ Groundwater in large parts of the NESCAUM region tends to be in fractured bedrock or unconsolidated sand and gravel aquifers, rather than clay-rich sediments.

C. Persistence/biodegradability of MTBE, other oxygenates, and BTEX

In addition to its higher mobility in groundwater, MTBE is relatively resistant to biodegradation compared to BTEX. Biodegradation of MTBE is a complex and evolving field of study, however, and under different conditions, various levels of MTBE biodegradation are known to occur, particularly under aerobic (oxygenated) as compared to anaerobic (oxygen-deprived) conditions. Early research indicated MTBE was resistant to biodegradation, but evidence is emerging that suggests MTBE is biodegradable under certain conditions or when certain microorganisms are present. Biodegradation of MTBE, however, may be hindered if alternative carbon sources are also available. The current consensus appears to be that MTBE is biodegradable under certain conditions, but rates of degradation are low relative to BTEX.³⁷ The study of MTBE biodegradation is a field of active research, so the current thinking on the relative importance of MTBE biodegradation is likely to evolve further with time.³⁸

Where known releases of gasoline occurred, monitoring wells detected MTBE levels that persisted for several years. For example, at an underground storage tank site in North Carolina, monitoring wells detected MTBE during 11 sampling events between January 1993 and April 1995.³⁹ The sampling period was several years after the tank had been removed in 1990. The monitoring wells detected MTBE levels that varied over time (one well ranged from 1,200 to 6,800 µg/L) and also detected BTEX during the sampling period. At another site in Missouri where an underground storage tank leaked gasoline into groundwater, three monitoring wells continued to detect MTBE over an approximately three-year period after tank removal. While all three monitoring wells detected MTBE, the amount detected varied temporally and spatially among the wells during the sampling period (reported ranges for the three wells were 700 to 14,000 µg/L,

³⁵ Squillace, *et al.*, revised 2/98, *supra* note 7, p. 5.

³⁶ Mace & Choi, 1998.

³⁷ Chapelle, F.H., 1999, Bioremediation of Petroleum Hydrocarbon-Contaminated Ground Water: The Perspectives of History and Hydrology, Ground Water, Vol. 37, pp. 122-132.

³⁸ For example, at the recent symposium "In Situ and On-Site Bioremediation: The Fifth International Symposium," held April 19-22 in San Diego, CA, an entire session was devoted to recent results on the bioremediation of MTBE (meeting agenda at <http://www.battelle.org/enviro/mnet/er/biosymp.html>).

³⁹ National Science and Technology Council, 1997, *supra* note 1, p. 2-45, *citing* Daniel, R.A., 1995, Intrinsic bioremediations of BTEX and MTBE: Field, laboratory and computer modeling studies: Raleigh, North Carolina, North Carolina State University, Department of Engineering, Thesis.

510 to 17,000 µg/L, and 13 to 2,600 µg/L).⁴⁰ The results described above indicate that MTBE can persist for years in groundwater, and that the detected concentrations (where associated with underground storage system releases) can vary by several orders of magnitude over time.

Some level of MTBE biodegradation under aerobic conditions has been observed, with the degradation product of *tert*-butyl alcohol (TBA), which is itself relatively resistant to biodegradation,⁴¹ but may be biodegraded by the same microorganisms that biodegrade MTBE. One study of streambed sediments at two gasoline-contaminated groundwater sites found that microorganisms under mixed anaerobic/aerobic conditions degraded both MTBE and TBA. The study found no degradation under strictly anaerobic conditions.⁴² Another study found evidence of MTBE decay under mixed aerobic-denitrifying conditions near the contamination source, but no MTBE decay in the downgradient aquifer.⁴³ Biodegradation with a relatively long half-life compared to BTEX was observed in a gasoline-contaminated aquifer in Ontario, Canada.⁴⁴

While data are sparse, the other ether fuel oxygenates (ETBE, DIPE, TAME) also appear to be relatively resistant to biodegradation compared to BTEX, at least under anaerobic conditions.⁴⁵ By comparison, researchers found some evidence that MTBE biodegradation could occur under anaerobic conditions in contrast to the other ether oxygenates, but speculated it was a relatively rare occurrence.⁴⁶ EtOH and MeOH, on the other hand, are generally much more prone to biodegradation.⁴⁷ Differences in the arrangement of carbon atoms and the chemically unreactive ether linkage are structural reasons why the ethers and TBA are relatively more resistant to biodegradation in groundwater.⁴⁸ The proclivity for EtOH biodegradation, however, may reduce biodegradation rates for BTEX compounds relative to BTEX biodegradation in the absence of EtOH. One study suggests that preferential microbial degradation of EtOH in groundwater can successfully compete against BTEX as an alternative carbon source, raising the possibility of larger BTEX contamination plumes in groundwater due to

⁴⁰ National Science and Technology Council, 1997, *supra* note 1, p. 2-45.

⁴¹ National Science and Technology Council, 1997, *supra* note 1, p. 2-61/62, and references therein.

⁴² Bradley, P.M., J.E. Landmeyer, and F.H. Chapelle, 1998, Aerobic Mineralization of MTBE and *tert*-Butyl Alcohol by Stream-Bed Sediment Microorganisms, *Envtl. Sci. & Technol.*, V. 33, pp. 1877-1879.

⁴³ Borden, R.C., R.A. Daniel, L.E. LeBrun IV, and C.W. Davis, 1997, Intrinsic Biodegradation of MTBE and BTEX in a Gasoline-Contaminated Aquifer, *Water Resources Research*, V. 33, pp. 1105-1115.

⁴⁴ Schirmer, M. and J.F. Barker, 1998, A Study of Long-Term MTBE Attenuation in the Borden Aquifer, Ontario, Canada: Ground Water Monitoring and Remediation, Spring 1998, pp. 113-122.

⁴⁵ Mormile, M.R., S. Liu, and J.M. Suffita, 1994, Anaerobic Biodegradation of Gasoline Oxygenates: Extrapolation of Information to Multiple Sites and Redox Conditions, *Envtl. Sci. & Technol.*, V. 28, pp. 1727-1732.

⁴⁶ Mormile, *et al.*, 1994, p. 1730.

⁴⁷ National Science and Technology Council, 1997, *supra* note 1, p. 2-60/62.

⁴⁸ Mormile, *et al.*, 1994.

delayed BTEX biodegradation.⁴⁹ As previously noted, there appears to be little research at present on the potential consequences of increased EtOH in groundwater.⁵⁰

MTBE and the other ether oxygenates also have relatively low Henry's Law constants relative to BTEX. The Henry's Law constant is the ratio of a chemical's concentration in air relative to its concentration in water at equilibrium. Chemicals with relatively high Henry's Law constants readily volatilize from water, and can be efficiently removed through aeration. Benzene, when compared to the ether oxygenates, has a rather large Henry's Law constant and is easier to remove from water through aeration than the ether oxygenates (as well as the alcohols).⁵¹

D. Comparison of MTBE detections in areas requiring reformulated gasoline (RFG) and areas not requiring RFG

A study in 16 U.S. cities analyzed storm water run-off for MTBE and non-oxygenate gasoline constituents between 1991 and 1995. Many of the cities covered by the study included areas that did not use MTBE in either oxygenated gasoline or reformulated gasoline (RFG), but MTBE may have been used as an octane enhancer. None of the cities were located in the Northeast or in California where MTBE use in oxygenated gasoline is high.⁵²

MTBE was detected in 41 of 592 storm water run-off samples (6.9%) in the 16 city study. For the samples with detectable MTBE, concentrations ranged between 0.2 and 8.7 µg/L, with a median of 1.5 µg/L.⁵³ Of the 41 MTBE detections, 25 (61%) occurred in cities not using oxygenated or reformulated gasoline. In these cities, MTBE presumably was used as an octane enhancer. The results suggest that if oxygenated gasoline requirements are abolished, low levels of MTBE may continue to contaminate groundwater in places using MTBE as an octane enhancer.

While MTBE is found in areas not requiring oxygenates in reformulated gasoline, the frequency of MTBE detection is higher in areas where oxygenated fuels are required. At a reporting level of 0.2 µg/L, the USGS National Water-Quality Assessment Program (NAWQA) found MTBE in 21% of 480 wells located in areas of the United States where MTBE is used as an oxygenate to abate air pollution (ozone or carbon monoxide). For the rest of the nation, MTBE detection frequency was 2%. Most detections were below the U.S. EPA drinking water advisory level, but levels above 5 µg/L and the lower limit of EPA's advisory level (20 µg/L) in RFG and oxygenated MTBE use areas were about

⁴⁹ Corseuil, H.X., C.S. Hunt, R.C.F. Dos Santos, and P.J.J. Alvarez, 1998, The Influence of the Gasoline Oxygenate Ethanol on Aerobic and Anaerobic BTX Biodegradation, *Water Research*, V. 32, pp. 2065-2072.

⁵⁰ U.S. Geological Survey, December 23, 1998, *supra* note 31.

⁵¹ National Science and Technology Council, 1997, *supra* note 1, p. 2-54.

⁵² National Science and Technology Council, 1997, *supra* note 1, p. 2-33, and references therein.

⁵³ National Science and Technology Council, 1997, *supra* note 1, p. 2-34/37 & Appendix 2. Note that the reporting level for MTBE changed from 1.0 to 0.2 µg/L during April 1994 of the study period.

10 times higher than the rest of the country. Population density, commercial and industrial land use, and other factors could influence the frequency of MTBE detections. When the NAWQA program controlled for these factors, the MTBE detection frequency was about 4 to 6 times higher in areas requiring RFG or oxygenated gasoline than in areas where the fuels were not required.⁵⁴ A recent study by the State of Maine also found a higher frequency of MTBE groundwater contamination in areas of the state where reformulated gasoline was required compared to areas where it was not (discussed in section III(B)(ii) *State-specific information from the NESCAUM region*).

The comparative MTBE differences between areas where RFG and oxygenated fuels are and are not required suggest that lowering MTBE concentrations in gasoline will lower the concentrations of MTBE found in ground and surface waters. This supposition is supported by MTBE solubility in water at varying MTBE volumes in gasoline. The amount of MTBE that will dissolve in water is a nearly linear function of the MTBE volume in gasoline at levels up to 15%. A proportional decrease in MTBE volume in gasoline leads to a similar proportional decrease in MTBE dissolved in water.⁵⁵ Table I shows the decreasing trend of MTBE dissolved in water at decreasing MTBE volumes in gasoline for a gasoline:water ratio of 1:10 (v/v).

Table I.
Amount of MTBE dissolved in water relative to MTBE in gasoline (% volume) for a gasoline:water ratio of 1:10 (v/v).⁵⁶

Volume % MTBE in gasoline	MTBE dissolved in water
5	1,760 mg/L
10	3,650 mg/L
15	5,140 mg/L

Based on the linearly decreasing trend, one can project decreasing MTBE concentrations in water at lower percentage MTBE volumes in gasoline. For example, for 2% MTBE in gasoline by volume, the maximum MTBE concentration in water would be about 700 mg/L for a gasoline:water ratio of 1:10 (v/v).

III. General synopsis of measured MTBE levels in NESCAUM region.

A. Susceptibility of groundwater sources in the NESCAUM region to contamination

In general, groundwater supplies in the NESCAUM region come from either fractured bedrock aquifers or sand and gravel aquifers, both of which are susceptible to

⁵⁴ Squillace, P.J., 1999, MTBE in the Nation's Ground Water: National Water-Quality Assessment (NAWQA) Program Results, Presentation to EPA Oxygenates Blue Ribbon Panel (April 29, 1999).

⁵⁵ Poulsen, M., L. Lemon, and J.F. Barker, 1992, Dissolution of Monoaromatic Hydrocarbons into Groundwater from Gasoline-Oxygenate Mixtures, *Environ. Sci. & Technol.*, V. 26, pp. 2483-2489.

⁵⁶ Poulsen, *et al.*, 1992, p. 2485 (Table II).

contamination by MTBE and other pollutants. Public water supply wells are more often located in sand and gravel aquifers compared to fractured bedrock aquifers due to the typically greater water yields. Private water wells commonly draw upon fractured bedrock aquifers, with some exceptions such as the Cape Cod area where shallow sand and gravel aquifers are more common. Flow paths within bedrock aquifers are generally not well known, but their vulnerability to contamination can be significant depending on the thickness of the overburden, degree of fracturing, and other factors.

As an example of the types of water supply sources in the northern NESCAUM region, approximately one-half of the eight million people living in Rhode Island, eastern Massachusetts, and large parts of Maine and New Hampshire get their drinking water from groundwater.⁵⁷ Of the four million served by groundwater sources (both public and private wells), about 35% receive water from bedrock supplies. The other 65% get drinking water from sand and gravel aquifers. About 90% of the public water supplies come from sand and gravel aquifers and 10% from fractured bedrock aquifers, with the exception of New Hampshire which gets about 35% of its public water supplies from bedrock aquifers.⁵⁸

Both types of aquifers are susceptible to MTBE and other pollutant contamination. In a sampling of over 1200 public and private water wells in Maine, the frequency of MTBE detections in surficial wells was not significantly different from bedrock wells.⁵⁹ In the study of groundwater within the Connecticut, Housatonic, and Thames River basins described previously, 25% of wells in surficial aquifers (26 out of 103 wells) and 23% of bedrock wells (7 out of 30) had detectable MTBE levels.⁶⁰

The presence of VOC contamination in groundwater does not appear to be directly related to well depth. The depth of water supply wells in which VOCs are detected does not significantly differ from the depth of water supply wells where VOCs are not detected. VOCs have been detected in well casings as deep as 605 feet, although this does not necessarily indicate that the VOCs are carried into deep bedrock wells by deep groundwater circulation. Rather, contamination may enter through leaky well seals or shallow fractures.⁶¹

Aquifers in the coastal plain of southern New Jersey are composed of unconsolidated sand and gravel aquifers. The surficial aquifers are highly vulnerable to contamination due to their permeability and direct hydraulic connection with the surface. There are also deeper lying confined aquifers beneath the surficial aquifers. The deeper aquifers are generally less susceptible to contamination but there may be locations where the aquifer

⁵⁷ This region corresponds to the New England Coastal Basin Study Unit of the U.S. Geological Survey National Water Quality Assessment Program.

⁵⁸ Oral communication from Joseph Ayotte, U.S. Geological Survey, New Hampshire-Vermont District, April 14, 1999.

⁵⁹ The Presence of MTBE and Other Gasoline Compounds in Maine's Drinking Water: A Preliminary Report, Maine Department of Human Services, Maine Department of Environmental Protection, Maine Department of Conservation (October 13, 1998) (Tables 4 and 9).

⁶⁰ Grady, 1997, *supra* note 9.

⁶¹ Grady, 1997, *supra* note 9.

outcrops at the surface, forming recharge areas that provide potential points of contamination. In northern New Jersey, fractured bedrock aquifers are more common. The aquifer types differ in geology (sandstones, mudstones, shales, crystalline bedrock), which will result in differences in geochemistry, degree of fracturing, and other physical characteristics. In general, however, the different types of fractured bedrock aquifers are all vulnerable to contamination, especially at shallower depths near the surface. Another type of aquifer in northern New Jersey was formed by the retreat of glaciers. These “valley-filled” aquifers are generally comprised of unconsolidated gravel, sand, or silt deposits that are highly permeable and susceptible to contamination from the surface.⁶²

In New York, sand and gravel aquifers are common, with valley-filled aquifers more sparsely distributed but having local importance as drinking water supplies. Both types are vulnerable to contamination from the surface. As with other areas of the NESCAUM region, fractured bedrock aquifers also exist within New York, with varying degrees of vulnerability to contamination depending on their physical characteristics. Long Island is somewhat unique in New York as having a glacially derived surficial aquifer with an underlying confined aquifer. The surficial sand and gravel aquifer is highly susceptible to contamination. The deeper underlying confined aquifer with older water is less susceptible to contamination.

In summary, the geological characteristics of many fractured bedrock and sand and gravel aquifers in the NESCAUM region are conducive to the spread of highly mobile pollutants such as MTBE and other gasoline oxygenates. While there may be some aquifers with geological characteristics less susceptible to contamination (e.g. an aquifer underlying an impermeable clay cap that hinders the downward migration of surface water), a large number of groundwater sources throughout the NESCAUM region appear to be less resistant to contamination.

B. Ambient air monitoring

Air monitoring data for MTBE in the NESCAUM region are limited. Three states, New Jersey, Rhode Island, and Vermont, collected ambient air MTBE data as part of VOC monitoring programs during 1997.

The New Jersey Department of Environmental Protection (NJ DEP) participates in the federal Urban Air Toxics Monitoring Program (UATMP) with a site located in the City of Camden. The program recently added MTBE as an analyte. The UATMP’s goal is to characterize the composition and magnitude of urban air pollution through extensive ambient air monitoring. The UATMP sites collect a 24-hour canister sample once every 12 days in or near 13 urban locations throughout the country. Each “year” of UATMP sampling begins in September and ends in August of the following calendar year.

⁶² Oral communication from Paul Stackelberg, U.S. Geological Survey, New Jersey District, April 16, 1999.

One complete year (September 1997 through August 1998) of MTBE ambient air information is available at the Camden, New Jersey site. During this period, 31 samples were analyzed for MTBE. Two samples were below the detection limit of 0.03 ppb by volume. The average concentration for the remaining 29 samples was 1.29 ppb by volume ($4.65 \mu\text{g}/\text{m}^3$); with a range of 0.28 to 3.74 ppb by volume (1.01 to $13.48 \mu\text{g}/\text{m}^3$).⁶³

In addition to the UATMP data, the USGS collected air samples at three sites in Gloucester County as part of a study to determine the cause, occurrence, and movement of MTBE and other VOCs through the urban hydrologic cycle. The detection level was similar at 0.02 ppb by volume.

During November 1996 through February 1998, the USGS collected atmospheric samples for 12 days at three sites in the study area. The median concentration of MTBE in the atmosphere ranged from 0.11 to 0.48 ppb by volume (0.40 to $1.73 \mu\text{g}/\text{m}^3$). The USGS inferred from this study that the atmosphere could be one of several sources of low-level concentrations of MTBE in shallow groundwater below $1 \mu\text{g}/\text{L}$.⁶⁴

Rhode Island measures MTBE in the ambient air at two sites – East Providence and West Greenwich. The Rhode Island Department of Environmental Management (RI DEM) collects 24-hour air samples once every six days year-round from the two sites. The East Providence sampling site is located immediately downwind of the Providence metropolitan area, but is not close to major roadways or point sources. The West Greenwich sampling site is a rural background site. Table II shows the median MTBE concentration observed in Rhode Island, along with the minimum and maximum concentrations detected at each site. The highest observed concentration was $8.70 \mu\text{g}/\text{m}^3$ at the East Providence site in 1997. The highest median MTBE concentration was $2.60 \mu\text{g}/\text{m}^3$, also at the East Providence site during 1997.

Table II.
Rhode Island MTBE Concentrations ($\mu\text{g}/\text{m}^3$).

Site location	Year	Minimum	Median	Maximum
East Providence	1998	0.22	1.91	6.79
	1997	0.25	2.60	8.70
West Greenwich	1998	0.47	0.32	1.34
	1997	0.00	0.40	3.36

The Vermont Department of Environmental Conservation (VT DEC) began collecting MTBE air data in September 1997 from five sites: Brattleboro, Burlington, Rutland, Underhill, and Winooski. The VT DEC collected and analyzed ten samples at each site during the last quarter of 1997. The samples were collected every 12 days over a 24 hour

⁶³ Communication from Gloria Post, New Jersey Department of Environmental Protection, July 6, 1999.

⁶⁴ Baehr, *et al.*, 1999, *supra* note 5.

period. Five of the six sites are located in urban-influenced areas, although not adjacent to major highways or point sources. The Underhill site is a rural background site.

Table III shows the VT DEC ambient air monitoring results for MTBE. For data collected during the last quarter of 1997, the maximum statewide MTBE ambient air level was $2.74 \mu\text{g}/\text{m}^3$ at the Brattleboro site. The maximum statewide MTBE median was $0.58 \mu\text{g}/\text{m}^3$ at the Brattleboro and Burlington sites. The Underhill site did not detect any MTBE at levels above the “non-detect” threshold of $0.11 \mu\text{g}/\text{m}^3$, which is one-half the minimum detection limit of $0.22 \mu\text{g}/\text{m}^3$. The VT DEC also analyzed for the oxygenates ETBE and TAME, but did not detect these compounds at any of the sampling sites.

Table III.
Vermont MTBE Concentrations ($\mu\text{g}/\text{m}^3$) during September-December 1997.

Site Location	Minimum	Median	Maximum	# ND	# Samples
Brattleboro	0.11	0.58	2.74	1	10
Burlington	0.11	0.58	1.05	2	10
Rutland	0.11	0.43	1.95	3	10
Underhill	0.11	0.11	0.11	10	10
Winooski	0.11	0.11	0.65	8	10

ND = Non-Detection. The minimum is $0.11 \mu\text{g}/\text{m}^3$ for all ND samples, which is one-half the minimum detection limit of $0.22 \mu\text{g}/\text{m}^3$.

The median values observed in ambient air monitoring by New Jersey, Rhode Island, and Vermont are consistent with median values observed during special studies in six cities during parts of 1992 and 1993. Three of the cities were located within the NESCAUM region: Albany, NY (median = $2.5 \mu\text{g}/\text{m}^3$), Boston, MA (median < $0.7 \mu\text{g}/\text{m}^3$), and Stamford, CT (median = $3.1 \mu\text{g}/\text{m}^3$).⁶⁵ Vermont, which does not require oxygenated reformulated gasoline, generally has lower MTBE levels in the ambient air compared to the other sampling sites.

Based on the MTBE ambient air concentrations of $3 \mu\text{g}/\text{m}^3$ or less from area sampling sites, rainfall recharging groundwater aquifers will have an equilibrium MTBE concentration of about $1 \mu\text{g}/\text{L}$ or less at 5°C .⁶⁶ The equilibrium concentration of VOCs in rainwater decreases by a factor of 3 to 7 when the temperature increases from 5°C (41°F) to 25°C (77°F), so the potential contribution of MTBE in rainwater recharging

⁶⁵ National Science and Technology Council, 1997, *supra* note 1, p. 2-29/33.

⁶⁶ As a general rule of thumb, 1 part per billion by volume of MTBE in air (1 ppb-v is equivalent to $3.6 \mu\text{g}/\text{m}^3$) has an equilibrium concentration in rainwater of $1 \mu\text{g}/\text{L}$ at 5°C (41°F). [Squillace, *et al.*, revised 2/98, *supra* note 7, p. 3.]

an underground aquifer will decrease during warm weather.⁶⁷ As a hypothetical worst-case scenario, if rainfall containing MTBE replaces entirely all the water in an underground aquifer, the concentration of MTBE in the aquifer will approach, but not exceed, the maximum concentration of MTBE in the rainfall (i.e., about 1 µg/L or less from rainfall). This is because the MTBE concentration cannot be greater than the highest concentration in the water recharging the aquifer unless some mechanism exists to preferentially remove water rather than MTBE once it reaches the aquifer. Researchers have not identified any such mechanism.

While the complete recharging of an aquifer may take hundreds of years, shorter flow paths for rainwater near the top of the water table can discharge to the surface in a matter of a few years. The USGS detected MTBE in recently recharged groundwater in which the majority of water samples were less than three years old, with a median age of one and a half years.⁶⁸ Ambient air monitoring at co-located sites indicated that MTBE concentrations in the air could potentially explain all but the highest few MTBE concentrations found in the shallow groundwater samples (minimum reporting level was 0.112 µg/L).⁶⁹ The study's authors concluded "if the atmosphere is the source [of MTBE in groundwater], then groundwater concentrations would be expected to remain at low-level concentrations not exceeding those in equilibrium with atmospheric concentrations." The detected MTBE levels in recently recharged groundwater were below 1 µg/L, which are well below current MTBE action levels.

Ambient air levels of MTBE can be higher near gasoline stations, parking lots, major roadways, and refineries, leading to higher concentrations in rainfall in the immediate area. Table IV summarizes ambient MTBE concentrations measured at gasoline stations in the NESCAUM region.

⁶⁷ Lopes and Bender, 1998, *supra* note 5.

⁶⁸ Communication from Paul Stackelberg, USGS-New Jersey District Office, July 28, 1999.

⁶⁹ Baehr, *et al.*, 1999, *supra* note 5.

Table IV.
Local ambient MTBE concentrations ($\mu\text{g}/\text{m}^3$) at service stations
in the NESCAUM region.⁷⁰

State/Source	Location	Minimum	Median	Maximum
New Jersey Service stations Stage II vapor recovery Full-service	Perimeter (x=15/16)	4	11	130
	Pumps (x=4/4)	432	1590	5770
	Breathing zone (x=4/4)	303	883	1870
New York Service stations Stage II vapor recovery Self-service	Perimeter (x=24/24)	7	25	299
	Pumps (x=6/6)	50	173	288
	Breathing zone (x=6/6)	278	739	2810
Connecticut Service stations Self-service	Perimeter (x=38/40)	4	50	505
	Pumps (x=9/10)	32	613	5410
	Breathing zone (x=10/10)	613	5410	9370

x = number of detections/number of samples.

Averaged over months to years, rainfall in the near vicinity of MTBE vapor sources (e.g., gasoline stations, parking garages, major roadways, refineries) could contribute higher MTBE levels to local groundwater relative to general background MTBE levels.⁷¹ For example, rainfall could contain MTBE levels of $\sim 30 \mu\text{g}/\text{L}$ or more at sites where local ambient air MTBE levels are consistently above $100 \mu\text{g}/\text{m}^3$. The higher MTBE concentration in rainfall, however, is very local and will likely be diluted as it spreads over a larger area within an aquifer. Therefore, locally high atmospheric concentrations of MTBE are not likely to lead to exceedances of MTBE action levels in groundwater, but could contribute to trace concentrations after dilution.

C. Measured MTBE levels in ground and surface waters

i. Regional studies

The USGS National Water-Quality Assessment Program (NAWQA) collected groundwater samples in 20 major basins across the U.S. during 1993-1994. In response to an EPA request to the states, the USGS also gathered additional MTBE data on groundwater drinking water supplies from seven states, and MTBE data on private wells from four states.⁷² In total, the USGS collected MTBE sampling data from 1,516 groundwater wells in 33 states.

⁷⁰ National Science and Technology Council, 1997, *supra* note 1, p. 2-32, Table 2.6, and references therein.

⁷¹ Squillace, *et al.*, revised 2/98, *supra* note 7, p. 3.

⁷² National Science and Technology Council, 1997, *supra* note 1, p. 2-37/39, Appendices 3 & 4.

Fourteen of the 33 states covered by the USGS surveys had detectable MTBE at some level in at least one water sample (minimum reporting levels in the surveyed states ranged from 0.2 to 5 µg/L). The MTBE detection frequency was about 5% (76 of the 1,516 wells). Within the NESCAUM region, groundwater samples from the states of Connecticut, Massachusetts, New Jersey, New York, and Vermont had detectable MTBE concentrations (minimum reporting levels in each state were 0.2 µg/L).

The majority of the MTBE detections occurred in shallow groundwater within urban areas (55 out of 204 well samples), with nearly half of the urban detections occurring in one urban area – Denver, CO (oxygenated gasoline has been in use in Denver since 1989). In land-use areas classified as agricultural, only 1.5% of the well samples had detectable MTBE levels (7 out of 524 well samples). For deeper aquifers or deeper parts of surficial aquifers, about 1.7% of the well samples had detectable amounts of MTBE (13 out of 781 well samples). The highest concentration from deeper groundwater was 7.9 µg/L from a location in New York State.⁷³

ii. *State-specific information from NESCAUM region*

The following is a synopsis of MTBE in groundwater in the individual NESCAUM states. The state-by-state synopsis, however, is not a comprehensive overview of the extent of MTBE contamination in different states within the NESCAUM region. Different states have different MTBE testing and reporting requirements, so no uniform basis exists for comparing the frequency of MTBE contamination between states. MTBE monitoring data in some states may be collected from surveys performed for special purposes that do not reflect a random sampling of waters within the state. For example, pesticide surveys of water wells may also report MTBE contamination, but wells suspected of having pesticide contamination are not necessarily representative of all wells within a state. Some states may also have incentive programs to assist well owners in cleaning up contaminated sites, which could encourage more frequent testing for MTBE relative to other states.

In addition to differences in sampling between states, reporting of MTBE has only recently been required on a consistent basis by many NESCAUM states. Minimum detection limits for MTBE have also changed over the years such that samples with low levels of MTBE that would not have been detected several years ago are now being reported. As a result, evaluation of trends in MTBE contamination over the past few years within an individual state is not possible due to differences in reporting and testing over time. The following state-by-state descriptions should be viewed only as a cursory overview of some of the available information, but not a rigorous survey of MTBE contamination in waters of the NESCAUM region.

⁷³ National Science and Technology Council, 1997, *supra* note 1, p. 2-39.

Connecticut

The Connecticut Department of Environmental Protection (CT DEP) maintains limited monitoring data on private water wells in Connecticut. The CT DEP keeps records on private water wells that exceed the state action level, which formerly was 100 µg/L before changing in March 1999 to 70 µg/L. The CT DEP monitors roughly 1000 private wells annually, but does not know the total number of privately tested water wells in the state. Private well owners may not report test results to the CT DEP unless the tests reveal MTBE levels above the state action level.

In 1998, the CT DEP knew of 22 private water wells with MTBE levels above the former action level of 100 µg/L. For these wells, the CT DEP believes the contamination sources are mainly releases from underground gasoline storage systems or fuel oil tanks (home heating).⁷⁴

Connecticut law requires all public water supplies to test for a variety of contaminants, and report the results to the Connecticut Department of Public Health (CT DPH).⁷⁵ The CT DPH issues annual drinking water reports based on the testing results, which include MTBE. Between 1997 and 1998, approximately 80% of the 607 community water supplies and about one-third of the approximately 647 non-transient non-community water systems tested for organic contaminants.⁷⁶

Of the public water supplies tested in 1997, 121 public water supplies detected some level of organic compound contamination, although only four detected contaminants above a state maximum contaminant level.⁷⁷ Thirty public water supplies detected MTBE at some level (31 wells detected MTBE, with one public water supply detecting MTBE at two different wells). Four water supplies detected MTBE above 10 µg/L. One well site in Killingly, CT exceeded the old MTBE action level of 100 µg/L (Connecticut has not set a maximum contaminant level for MTBE). The site recorded an MTBE concentration of 210 µg/L, which occurred concurrently with a benzene level of 1.4 µg/L (this is below the benzene maximum contaminant level of 5 µg/L). Concurrent detection of MTBE and benzene suggests a nearby gasoline release as the source of contamination.

Of the public water supplies tested in 1998, 159 public water supplies detected some level of organic compound contamination, with 10 supplies testing above a state maximum contaminant level or action level.⁷⁸ The increase in contaminant detections may be due to increased testing of non-community (nonresidential) supplies in 1998 by the CT DPH. Of the 159 public water supplies detecting some form of organic

⁷⁴ Communication from the Connecticut Department of Environmental Protection, March 11, 1999.

⁷⁵ Connecticut General Statutes Sec. 25-39a.

⁷⁶ Communication from the Connecticut Department of Public Health, April 15, 1999.

⁷⁷ Report per Section 25-39a of the Connecticut General Statutes: Monitoring, Health Risks, and Treatment Costs for Organic Chemicals in Public Drinking Water for the Year 1997, Connecticut Department of Public Health (February 1998).

⁷⁸ Report per Section 25-39a of the Connecticut General Statutes: Monitoring, Health Risks, and Treatment Costs for Organic Chemicals in Public Drinking Water for the Year 1998, Connecticut Department of Public Health (February 1999).

contamination in 1998, 28% (45 of 159 systems) detected MTBE, with a total number of 51 wells detecting MTBE (some water supplies detected MTBE in more than one well within their systems). Thirteen water supplies detected MTBE above 10 µg/L in at least one system well. Four water supplies detected MTBE above the former state action level of 100 µg/L. The maximum MTBE concentration was 17,000 µg/L in Brookfield, followed by 3,982 µg/L in Wilton, 400 µg/L in Durham, and 240 µg/L in Salem. The Salem site detected benzene concurrently with MTBE, and the Wilton site detected toluene. The concentrations were below state maximum contaminant levels for benzene and toluene. Table V summarizes the MTBE contamination levels in Connecticut public water supplies in 1997 and 1998.

Table V.
Summary of MTBE levels (µg/L) in Connecticut public water supplies
during 1997 and 1998.*

Year	# sites with MTBE at some level	Minimum	Median	Maximum
1998	51	0.6	5.6	17,000
1997	31	0.5	3	210

*Minimum, median, and maximum MTBE levels are based only on sites detecting MTBE. In 1997, 30 water supplies detected MTBE at 31 sites (one supply detected MTBE in two different wells). In 1998, 45 water supplies detected MTBE at 51 sites (several water supplies detected MTBE at more than one well within the same system). The majority of testing public water supplies did not detect MTBE.

Maine

Perhaps the first study identifying MTBE in groundwater from a gasoline release as a public health issue has come from Maine. In 1984, Maine first detected MTBE in an 80-foot drilled water well located in rural southwestern Maine, and the contamination spread to several nearby wells in the following months. This was before the oxygenated gasoline requirement of the 1990 Clean Air Act Amendments. Maine identified the source as a farmer's storage tank leaking gasoline directly into the underlying fractured bedrock. Analysis of the gasoline indicated it was leaded gasoline containing 3% MTBE by volume, presumably as an octane enhancer. Maine was still detecting MTBE at significant levels (>10,000 µg/L) in local groundwater two years after the leak was discovered.⁷⁹

In 1998, Maine completed a survey of the occurrence of MTBE and other gasoline constituents in drinking water sources across the state.⁸⁰ The State of Maine sampled 951 randomly selected household wells and other household water supplies (e.g., springs and

⁷⁹ Garrett, P., M. Moreau, and J.D. Lowry, 1986, MTBE as a Ground Water Contaminant; Proceedings of the 1986 Conference on Petroleum and Organic Chemicals in Ground Water, National Water Well Association and American Petroleum Institute, Houston, TX, p. 227.

⁸⁰ The Presence of MTBE and Other Gasoline Compounds in Maine's Drinking Water: A Preliminary Report, Maine Department of Human Services, Maine Department of Environmental Protection, Maine Department of Conservation (October 13, 1998).

lakes) and 793 regulated non-transient public water supplies. The sampling looked for five gasoline constituents – MTBE, benzene, toluene, ethylbenzene, and xylenes. The minimum reporting level was 0.1 µg/L for MTBE, benzene, toluene and ethylbenzene, and 0.3 µg/L for total xylenes.

Private water supplies. The Maine study found the following for private water supplies:

- 15.8%, or 150 of the 951 private wells, contained MTBE at some detectable level.
- 1.1% of the sampled waters contained MTBE above the Maine drinking water standard of 35 µg/L.
- 92.3% of the sampled private wells had either undetectable MTBE levels or were below 1 µg/L, and 6.6% were between 1 µg/L and 35 µg/L (i.e., 98.9% of water samples were below Maine's MTBE drinking water standard).
- Compared to MTBE, the BTEX compounds were infrequently detected and well below health-based standards.
- In areas of high population density (greater than 180 people per square mile), the risk of MTBE detection was 1.3 times higher in areas requiring RFG compared to other areas.
- In areas of low population density (less than 180 people per square mile), the risk of MTBE detection was 2.0 times higher in areas requiring RFG compared to other areas.
- In areas requiring RFG, the risk of MTBE detection was 1.4 times higher in areas of high population density compared to other areas.
- In areas not requiring RFG, the risk of MTBE detection was 2.1 times higher in areas of high population density compared to other areas.

Public water supplies. The Maine study found the following for public water supplies:

- 16%, or 125 out of 793 public water supplies, contained MTBE at some detectable level.
- No public water supplies had MTBE levels above the state drinking water standard of 35 µg/L, although MTBE levels above 35 µg/L have previously been detected in Maine public water supplies prior to the period covered in the study.
- 93.9% of the sampled public water supplies had either undetectable MTBE levels or were below 1 µg/L, and 6.1% were between 1 µg/L and 35 µg/L.
- Compared to MTBE, the BTEX compounds (with the possible exception of toluene) were infrequently detected and well below health-based standards. Toluene may have been detected relatively more frequently at low levels, but more than 80% of toluene detections occurred in reprocessed samples that did not receive confirmatory sampling by trained field staff.⁸¹

⁸¹ Due to logistical challenges in doing an MTBE study within a four-month period, Maine made an effort to reduce the need for additional field sampling. The State used pre-existing data from water samples already collected and submitted by public water supplies as part of their routine compliance monitoring. The original gas chromatograph/mass spectrometer (GC/MS) data tapes were initially calibrated for MTBE and BTEX at minimum reporting levels of 1.0 µg/L and 0.5 µg/L, respectively. For the MTBE study,

- In areas of high population density (greater than 180 people per square mile), the risk of MTBE detection was 4.1 times higher in areas requiring RFG compared to other areas.
- In areas of low population density (less than 180 people per square mile), the risk of MTBE detection was 1.7 times higher in areas requiring RFG compared to other areas.
- In areas requiring RFG, the risk of MTBE detection was 1.6 times higher in areas of high population density compared to other areas.
- In areas not requiring RFG, population density did not appear to be a risk factor.

The frequency distributions of MTBE detections in Maine private wells and public water supplies are shown in Tables VI-a and VI-b, along with a comparison to results from several USGS studies in the Northeast. Table VI-a is a straightforward comparison of the frequency distributions of MTBE concentrations between the Maine and USGS studies, and suggests that they are similar across the studies.

Table VI-a.
Comparison of frequency distributions for MTBE concentrations
for the Maine and USGS studies.

Concentration Range (µg/L)	Maine Private Wells N = 946 (95% CI)	Maine Public Water Supplies N = 793 (95% CI)	USGS Studies N = 376 (95% CI)
< 0.2	85.0%	85.1%	82.2%
0.2 – 5	12.0% (10-14%)	13.6% (11-16%)	16.2% (13-20%)
5 – 35	1.9% (1.1-2.3%)	1.3% (0.6-2.3%)	1.0% (0.3-2.7%)
> 35	1.1% (0.5-1.9%)	0.0% (0.0-0.5%)	0.5% (0.06-1.9%)

From Table 12, p. 11 of Maine study (footnote 39).

N = Number of samples.

95% CI = 95 percent confidence interval. Note that the smaller number of observations at higher MTBE concentrations (>5 µg/L) makes conclusions about differences between the Maine and USGS results less meaningful, as reflected by the considerable overlap in the 95% confidence intervals.

Maine “reprocessed” the GC/MS data tapes using laboratory calibration check standards in order to estimate concentrations down to 0.1 µg/L for MTBE, benzene, toluene, and ethylbenzene, and 0.3 µg/L for total xylenes. For GC/MS data tapes that were reprocessed in this manner and estimated to have detectable MTBE equal to or above 0.1 µg/L, Maine sent trained field staff for confirmatory MTBE sampling at the relevant public water supply. Because the study’s focus was on MTBE, reprocessed samples were not confirmed if only toluene without MTBE was detected. Because 80% of the toluene detections occurred in reprocessed GC/MS data tapes and were generally below 0.5 µg/L, these results may reflect contamination during the sample collecting or testing process, rather than in the public water supply itself. Errata (March 8, 1999), The Presence of MTBE and other Gasoline Compounds in Maine’s Drinking Water: Preliminary Report – October 13, 1998.

Because the overall MTBE detection rates from the USGS studies and the Maine study may reflect differences in population densities across the Northeast, the Maine study also compares its results to the USGS studies after normalizing for population density (Table VI-b). The detection frequencies are again similar. The paucity of samples at low population densities from the USGS studies makes conclusions about differences between the studies less meaningful at the lower ranges, as reflected by the broad 95 percent confidence intervals with considerable overlap among the sampling groups.

Table VI-b.
Comparison of frequencies of detection by population density for USGS studies and Maine studies with private residential and public water supplies.

Population Density (people/square mile)	Maine Private Wells (95% CI)	Maine Public Water Supplies (95% CI)	USGS Studies (95% CI)
< 40	13.3% (9-18%)	8.3% (5-13%)	3.2% (<1-17%)
40 – 80	9.2% (6-14%)	13.6% (8-21%)	6.5% (1-18%)
80 – 180	14.4% (10-20%)	20.3% (14-28%)	11.1% (6-20%)
180 – 1000	20.9% (16-27%)	24.0% (14-26%)	24.5% (18-32%)
> 1000	28.1% (14-47%)	24.2% (11-42%)	27.6% (17-41%)

From Table 13, p. 11 of Maine study (footnote 39).

95% CI = 95 percent confidence interval. Note that the smaller number of samples from the USGS studies at lower population densities makes distinctions between the Maine study and USGS studies less meaningful, as indicated by the broad 95% confidence intervals.

Massachusetts

The Massachusetts action level for MTBE in drinking water is 70 µg/L. Massachusetts currently does not require testing and reporting of MTBE contamination in public water supplies, but is in the process of developing regulations to require such testing and reporting in the future. The Massachusetts Department of Environmental Protection (MA DEP) has kept limited records of MTBE contamination since 1993 based on voluntary reporting by public water supplies, but the agency does not know the total number of public water supplies that tested and reported for MTBE. There are about 1,600 public water supplies in Massachusetts, which represents about 35% of total water systems. The public water supplies serve about 7 million people out of the 9 million state population. The MA DEP does not have MTBE information from private water wells.

Table VII presents a summary of MTBE contamination in Massachusetts public water supplies, but should be viewed with at least one caveat in mind. Because testing and reporting are voluntary, any analysis of the scope and time trends of MTBE

contamination in public water supplies will be based on a limited and self-selected group of public water supplies (i.e., those that voluntarily reported).

Table VII.
Summary of MTBE levels (µg/L) in Massachusetts public water supplies.*

Year	# water supplies reporting MTBE at some level	Minimum	Median	Maximum
1998	31	0.5	1.6	230
1997	29	0.5	2	690
1996	22	0.5	1	17
1995	9	2	2	68
1994	9	0.5	1.2	99
1993	9	0.7	1.7	80

*Minimum, median, and maximum MTBE levels are based only on public water supplies that voluntarily reported MTBE levels to MA DEP. The total number of public water supplies testing for MTBE is not known.

The highest MTBE concentrations occurred in 1997 and 1998 in Monson, MA at a well two blocks from the site of a large gasoline spill. The BTEX compounds benzene and ethylbenzene were also detected at the well.⁸² Three other wells in Massachusetts also detected MTBE above the 70 µg/L state action level that was attributable to gasoline spills.

New Hampshire

Under rules enacted in 1993, New Hampshire requires approximately 1125 community and non-transient public water systems to test for VOCs on an annual basis. Public water systems, however, can obtain three or six-year waivers from the annual testing requirements through New Hampshire's source water protection program. The State does not require transient water systems to test for VOCs, so any data reported for these systems may not be representative of the entire group. Testing is performed either by New Hampshire-certified private labs or the State Laboratory at the New Hampshire Department of Environmental Services (NH DES). The State laboratory has reported MTBE values since the mid-1980s. The State did not require private labs to report MTBE until October 1998.

As of March 29, 1999, New Hampshire had 195 water systems (of which 24 are no longer active) with MTBE detections. The 195 water systems can be further broken down into varying levels of MTBE detections shown in Table VIII. The term "active" refers to whether the system still meets the definition of a public water supply (defined as a system that is designed to serve 25 or more people or has 10 or more service connections 60 or more days of the year).

⁸² Communication from the Massachusetts Department of Environmental Protection, 1999.

Table VIII.
Break-down of MTBE concentration ranges detected in New Hampshire water supplies as of March 29, 1999.

Range of MTBE detections (µg/L)	Number of systems
Currently below detection limits	59 systems
0.5 – 5	106 systems (Only 96 are active.)
5.1 – 15	20 systems (Only 19 are active.)
15.1 – 20	1 system (This system shows a decreasing trend.)
20.1 – 40	6 systems (Only three of these systems are active of which one has treatment and another is showing a decreasing trend. The third one has not been confirmed yet.)
40.1	3 systems (Only one system is active and has switched to using bottled water.)

Many of the systems with low level detections of MTBE do not have well identified contamination sources although surface water sources can probably attribute their low levels to the use of recreational motor boats and other water craft on the reservoirs.⁸³

New Jersey

The New Jersey Drinking Water Quality Institute's development of a drinking water standard (Maximum Contaminant Level, MCL) for MTBE began in the mid-1980s in response to MTBE's detection in New Jersey drinking water surveys (discussed below). This was prior to MTBE's use as an oxygenate to reduce air pollution (it was being used as an octane booster).

New Jersey promulgated a Maximum Contaminant Level (MCL) of 70 µg/L for MTBE in 1996, pursuant to the A-280 Amendments to the New Jersey Safe Drinking Water Act. New Jersey also required MTBE monitoring by all water supplies at this time. Private laboratories do testing of public water supplies in New Jersey.

Following adoption of the MCL standard for MTBE, the New Jersey Bureau of Safe Drinking Water has been collecting data on MTBE in public water supplies since 1997. The data presented in Table IX are from approximately one year of sample results (July 1997-September 1998). During this time period, approximately 400 of 614 public community water supplies and approximately 400 of 1100 non-transient non-community water supplies submitted sampling results. The regulations require that samples are to come from the point of entry to the distribution system.

⁸³ Communication from the New Hampshire Department of Environmental Services, April 13, 1999.

Table IX.
MTBE Detections in New Jersey Water Supplies in July 1997 to September 1998.

MTBE Concentration Range	Community Water Systems	Nontransient Noncommunity Water Systems
below detection limit (<0.5 µg/L)	341 (85%)	33 (84%) 3
0.5 to 20 µg/L	59 (15%)	62 (16%)
20 to 70 µg/L	0	1 (0.25%)
over 70 µg/L	0	1 (0.25%)

For community water systems, New Jersey found MTBE above the detection limit of 0.5 µg/L in samples from 59 community water systems out of approximately 400 that sampled (15%). (About 200 community water systems were not required to sample in this time period.) Samples from public community water supplies are normally finished water. The MTBE concentrations in the community supplies ranged up to 8.4 µg/L, and none approached the drinking water MCL of 70 µg/L.

For non-transient non-community systems, there were detections in 64 systems out of the 397 systems reporting. In these systems, there is likely to be no water treatment. The highest MTBE concentration detected was 130 µg/L, and this was the only sample that exceeded the MCL of 70 µg/L.⁸⁴

In addition to the recent monitoring by the New Jersey Bureau of Safe Drinking Water, the New Jersey District Office of the U.S. Geological Survey (USGS) collects MTBE data in New Jersey ground and surface waters as part of several projects performed by the USGS. Since 1983, the USGS has run statewide ambient groundwater and surface water monitoring networks in cooperation with the NJ DEP. A goal of the monitoring networks is to characterize the quality of groundwater and surface water and its relationship to land-use patterns. The monitoring also seeks to assess groundwater impacts on surface water quality. The networks consist of 115 surface water stations and 22 groundwater stations. The surface water stations are sampled four times a year, and are a mix of sites sampled every year and new sites created each year. The groundwater stations are sampled once a year, and the sites are changed each year.

The USGS also collects MTBE data as part of National Water Quality Assessment (NAWQA) projects and other special studies underway in New Jersey. One of the USGS special studies is described in Section II (Cranberry Lake and surrounding lakes in Sussex County, New Jersey). In addition to the Cranberry Lake study, two other recent

⁸⁴ Communication from Gloria Post, New Jersey Department of Environmental Protection, July 6, 1999.

USGS studies in New Jersey assessed MTBE and other VOCs in seven surface streams and an underground aquifer.

In a study of seven New Jersey streams, the USGS detected MTBE in 78% of the stream water samples collected from April 1996 to April 1997 (87 out of 112 samples).⁸⁵ MTBE was the most frequently detected VOC, followed by chloroform (63%), trichloroethene (51%), 1,1,1-trichloroethane (41%), and tetrachloroethene (35%). The median concentration for samples with detectable MTBE was 0.42 µg/L, with a maximum concentration of 4.8 µg/L (non-detect value = 0.1 µg/L). Detection frequency and median concentration of MTBE were highest in the Bound Brook drainage basin, which has the highest percentage of urban-industrial land-use out of the seven stream drainages assessed in the study.

Median concentrations of MTBE were consistently higher in the stream samples during the cooler months of the year (October-March) than in the warmer months (April-September). The higher concentrations in the cooler months are probably a reflection of the greater partitioning of MTBE from air into water at lower temperatures. Higher concentrations could also be the result of refiners adding more MTBE to gasoline sold in New Jersey in the winter than in the summer.

The USGS also sampled groundwater for MTBE and other VOCs in a limited study area in the New Jersey Coastal Plain. The USGS collected water samples from a network of 72 wells in a recently recharged groundwater system in southern New Jersey.⁸⁶ Forty-four percent of the wells had detectable MTBE levels, making it the second most frequently detected VOC in the aquifer behind chloroform (80.5%). The median concentration in samples with detectable MTBE was 0.20 µg/L with a maximum of 43.8 µg/L (minimum detection level = 0.1 µg/L). The USGS postulated that the widespread presence of MTBE in the aquifer could be due to atmospheric deposition of MTBE partitioned into rainfall, MTBE in urban storm water run-off from roadways and parking lots, or releases from underground gasoline storage systems. In a subsequent investigation, the USGS found that atmospheric MTBE concentrations could potentially explain all but the few highest MTBE concentrations found in the shallow groundwater of the study area, although migration from a distant gasoline release site could not be ruled out as a source.⁸⁷

Table X presents an overview of MTBE detections by the USGS in ground and surface waters of New Jersey.⁸⁸ The data are from the Ambient Ground-Water Monitoring Network as well as several special studies performed by USGS. The number of detections may include several samples from the same site.

⁸⁵ Reiser, R.G. and A.K. O'Brien, 1998, Occurrence and seasonal variability of volatile organic compounds in seven New Jersey streams, U.S. Geological Survey Water-Resources Investigations Report 98-4074.

⁸⁶ Stackelberg, *et al.*, 1997, *supra* note 14.

⁸⁷ Baehr, *et al.*, 1999, *supra* note 5.

⁸⁸ Communication from the USGS New Jersey District Office, January 15, 1999.

Table X.
Summary of MTBE levels (µg/L) in New Jersey ground and surface waters gathered by the USGS New Jersey District Office.

Year	# of samples	# of MTBE detections	Median of detected concentrations*	Maximum
Ground Water				
1998	102	35	0.19	4.1
1997	183	55	0.67	30.2
1996	89	34	0.21	43.8
1995	23	5	0.3	2.3
1994	19	3	0.5	2.1
Surface Water				
1998	161	112	1.09	29
1997	98	94	0.52	16
1996	107	80	0.41	4.9

*The minimum detection limit varied by sample from 0.5 to 0.1 µg/L. The USGS confirmed the presence of MTBE in some samples but at levels below the minimum detection limits. The median detected concentration includes all samples confirmed to have MTBE present, including those estimated to be below the minimum detection limits.

New York

Private laboratories generally do compliance monitoring for large public water supplies in New York. Prior to July 1998, New York did not require testing and reporting of MTBE. The New York State Department of Health (NY DOH) now asks for MTBE information from groundwater supplies serving over 10,000 people. The NY DOH is currently gathering testing results from the private labs to assess the presence of MTBE in public water supplies.

In addition to private testing of large public water supplies, New York does its own water quality surveys with testing at New York's Wadsworth Laboratories. The Wadsworth Laboratory performs compliance monitoring primarily for small public water systems as well as pesticide surveys in targeted agricultural, surface water areas. Because the pesticide surveys focus on agricultural areas, the sampling data reported for MTBE are not a representative data set for the State. Table XI presents a synopsis of MTBE testing results from the Wadsworth Laboratory.⁸⁹

⁸⁹ Communication from the New York State Department of Health, February 24, 1999.

Table XI.
Summary of MTBE levels (µg/L) in New York waters analyzed by Wadsworth
Laboratory, 1996-1998.

Year	# of samples*	# of detections*	# detections 10µg/L*	Minimum (µg/L)**	Maximum (µg/L)
1998	381	16	3	1	33
1997	404	17	1	1	17
1996	282	5	5	14	66

*The number of samples and detections includes multiple samples from the same well site.

**In 1996, the minimum detection limit reported for all samples was 10 µg/L. In 1997, samples could have a minimum detection limit of either 10 µg/L or 1 µg/L. In 1998, all samples had a minimum detection limit of 1 µg/L. As a result, MTBE concentrations below 10 µg/L in a portion of water samples taken in 1996 and 1997 will have missed detection relative to samples tested in 1998.

Rhode Island

Rhode Island requires VOC testing in public water supplies, which is performed by the Rhode Island Department of Health (RI DOH). The MTBE health advisory level in Rhode Island is 40 µg/L. While the State does not require testing specifically for MTBE, it is reported as a result of the State tests. New public water supplies are required to submit samples for the first four quarters (3 months) of operation. If no VOCs are detected, then water samples are submitted annually for the next three years. If VOCs continue to be absent, then testing is performed triennially after the annual testing period.

Table XII presents MTBE monitoring results for Rhode Island public water supplies that are collected by the RI DOH.⁹⁰ The supplies include both groundwater and surface water supplies.

⁹⁰ Communication from the Rhode Island Department of Health, February 22, 1999.

Table XII.
Summary of MTBE in Rhode Island public water supplies (ground and surface waters) gathered by the Rhode Island Department of Health.

Year	# of samples	# of MTBE detections*	Median of detected concentrations (µg/L)**	Maximum (µg/L)
1998	197	59	5	57
1997	143	32	8	62
1996	241	34	13	75
1995	167	15	10	97
1994	88	9	6	12
1993	101	3	4	5
1992	112	2	--	1
1991	312	28	2	9
1990	580	35	8	3260
1989	111	7	21	48

*Includes MTBE detections in multiple samples from the same water supply collected at different times during a given year.

**The minimum detection limit varied by sample and year from 10 to 0.1 µg/L. Samples not detecting MTBE below the minimum detection limit are not included in determining the median MTBE concentration.

The RI DOH also tests private wells, but only if there is reason to believe contamination may be occurring from a spill event such as a gasoline storage system release. Therefore, the testing results do not represent a random sampling of private wells in Rhode Island. Instead, the State tests private wells thought most likely to be contaminated.

Table XIII presents partial results from private well testing in Rhode Island. The table presents only information pertaining to private wells exceeding the State health advisory level of 40 µg/L. The RI DOH found a larger number of private wells with MTBE contamination at lower levels, but because the tested private wells are not randomly selected, it is difficult to draw inferences about the frequency of MTBE contamination.

Table XIII.
Private water well supplies in Rhode Island known to exceed the State 40 µg/L
MTBE health advisory level.⁹¹

Year	# of wells exceeding 40 µg/L MTBE	Maximum MTBE (µg/L)
1998	3	150
1997	6	400
1996	15	2850
1995	3	170
1994	3	126
1993	8	237
1992	1	130
1991	9	3000
1990	18	1500
1989	6	230
1988	2	120
1987	1	213

Of special note in Tables XII and XIII is the presence of MTBE in Rhode Island drinking water prior to November 1995 when reformulated gasoline requirements first began in the State.⁹² The water supply testing indicates that MTBE was contaminating public and private drinking water sources prior to the oxygenated gasoline requirement in the 1990 Clean Air Act Amendments.

Vermont

There are 76,445 known drinking water supplies in Vermont. Of these, 1,312 are public water supplies and 75,133 are private supplies. Vermont requires only certain public water supplies to test for MTBE. Of the 1,312 public water supplies, 650 must perform VOC testing as part of their compliance monitoring, which invariably includes MTBE. Public water supplies initially must do VOC testing for four consecutive quarters. If no detections occur, the sampling frequency is reduced to once a year. If no detections occur for three consecutive years, then testing is reduced to every three years.

For the water supplies that test, about 80% of public supplies use the Vermont Department of Health (VT DOH) State lab, while about 90% of private supplies use certified private labs. The minimum detection limit in MTBE testing performed by the VT DOH lab is 0.5 µg/L, and the minimum detection limit for most private labs is 1 µg/L.

⁹¹ Communication from the Rhode Island Department of Health, April 2, 1999.

⁹² Communication from the Rhode Island Department of Environmental Management, Office of Air Resources, April 9, 1999.

Although the sale of oxygenated gasoline is not required in Vermont, water supply testing finds MTBE contamination in Vermont drinking water.⁹³ As of March 1999, samples from approximately 210 drinking water supplies contained MTBE at some level. About 95% of the 650 public water supplies have been tested for MTBE. Thirty-five (approximately 5.5%) found detectable concentrations of MTBE. Three supplies detected MTBE above the State health advisory level of 40 µg/L.

The vast majority of drinking water supplies in Vermont are private supplies that have no State monitoring requirements. Sampling from private wells typically occurs only if they are located near an identified hazardous waste site. Approximately 175 private water supplies detected MTBE at some level, with less than 1% of all private supplies being tested. Of the approximately 175 private supplies with detectable MTBE, the State estimates that about 40 supplies are above the 40 µg/L Vermont health advisory level. The State does not know the frequency of MTBE contamination in private supplies because much of the testing is in response to known nearby hazardous waste sites, which is not representative of the general population of private supplies. If a similar detection frequency in public water supplies applies to the private water supplies, then there could be many more additional private supplies contaminated by MTBE that have not yet been identified.

IV. Summary

MTBE is typically one of the most common VOCs detected in ground and surface waters in the eight-state NESCAUM region. Frequent low-level MTBE concentrations below 10 µg/L suggest possible contamination from sources other than leaking underground storage systems, such as stormwater run-off, small surface spills, and deposition from air in rainfall. Low-level MTBE contamination, however, could also be due to distant underground gasoline releases in which much of the contamination has been attenuated through dilution as it travels through the aquifer.

While deposition from air is a possible source of low-level MTBE concentrations in groundwater, the level of contamination is highly unlikely to exceed drinking water standards or public action levels based on measured ambient air concentrations of MTBE. Levels above MTBE drinking water standards are more likely due to gasoline releases from point sources such as underground storage tanks and pipelines, or gasoline spillage events, including spills of less than 10 gallons.

MTBE is fairly soluble in groundwater and can move through the groundwater table at a similar speed as the water itself. In contrast, BTEX compounds are more likely to attach to surrounding materials, retarding their speed through the aquifer. Therefore, monitoring wells may detect MTBE from a gasoline spill before BTEX arrives. At low levels of MTBE contamination (<10 µg/L), water samples often do not contain detectable BTEX levels. At higher levels of MTBE contamination (>30 µg/L) from large gasoline

⁹³ Communication from the Vermont Department of Environmental Conservation, March 26, 1999.

releases (hundreds of gallons or more), BTEX is often detected concurrently or at some later time as the main gasoline plume migrates towards the sampling site. MTBE from small surface spills (on the order of tens of gallons or less) may also reach these higher levels with only low or no levels of concurrent BTEX. From the Maine experience, these small spills can exceed drinking water standards, but are fairly transient compared to larger gasoline releases. Other ether oxygenates, such as ETBE, DIPE and TAME will behave similarly to MTBE based on their relatively greater solubility in water compared to BTEX.

MTBE is relatively resistant to biodegradation, as are the other ether fuel oxygenates and the alcohol TBA, when compared to BTEX biodegradation. Researchers find that MTBE is biodegradable in the presence of some microbes or under certain conditions, such as aerobic (oxygenated) conditions, but the rates of degradation are low relative to BTEX. Biodegradation of BTEX, EtOH, and MeOH, by contrast, occurs more readily under a variety of conditions, including anaerobic (oxygen-deprived). The combination of greater mobility in groundwater and relatively greater resistance to biodegradation results in MTBE generally occupying a greater volume within an aquifer than BTEX. The other ether oxygenates ETBE, DIPE, and TAME, and the alcohol TBA likely behave similar to MTBE. EtOH and MeOH, while very soluble in water, are more susceptible to biodegradation, and may not persist as long in groundwater relative to MTBE and the other fuel oxygenates. There are indications, however, that EtOH may be a more attractive carbon source for microbes than BTEX, such that the presence of EtOH in gasoline plumes may delay the onset of BTEX biodegradation compared to gasoline plumes where EtOH is absent. The study of fuel oxygenate biodegradation is a field of active research that continues to evolve with time.

MTBE exists in ground and surface water in locations where oxygenated gasoline is and is not required for sale. Where the oxygenate requirement does not exist, gasoline refiners presumably add MTBE at some reduced volume to serve as an octane booster.

MTBE contamination exists at a number of sites across the eight-state NESCAUM region. Comparing the extent of MTBE contamination across the eight-state NESCAUM region is difficult due to different reporting requirements and amounts of historical data collected by the NESCAUM states. Enough data do exist, however, to indicate that MTBE is one of the most commonly detected VOCs in ground and surface waters across the region. Other common pollutants found with comparable frequency include chloroform and pesticides. Most MTBE contamination levels are below existing State health advisory or action levels, but water sampling finds much higher concentrations often associated with known gasoline spillage sites.

MTBE contamination can occur in the absence of an oxygenate requirement. Significant levels of MTBE contamination in Maine and Rhode Island water supplies occurred prior to 1992, which is before the Clean Air Act required the sale of oxygenated gasoline. In addition, MTBE contamination occurs in parts of New Hampshire, Maine and Vermont where the sale of oxygenated reformulated gasoline is not required. This suggests that MTBE contamination can occur even if there is no oxygenated gasoline requirement.

Decreasing the volume of MTBE added to gasoline, however, should lead to proportional decreases in MTBE dissolved in water after gasoline spills, particularly small surface spills of several gallons. While MTBE concentrations (along with BTEX) will remain high near the sites of large gasoline releases, the extent of low-level contamination observed over the larger NESCAUM region should be reduced to even lower levels.

Northeast States for Coordinated Air Use Management

Attachment III

**Air Quality, Fuel Supply and Cost
Impacts of MTBE and its Alternatives**

August 1999

Table of Contents

I. INTRODUCTION	6
II. BACKGROUND AND CONTEXT	7
A. WHAT IS REFORMULATED GASOLINE?	7
B. THE ROLE OF MTBE IN REFORMULATED GASOLINE	10
C. OXYGENATE ALTERNATIVES TO MTBE	14
D. NON-OXYGENATE MTBE ALTERNATIVES	16
III. MTBE SUPPLY AND DISTRIBUTION ISSUES	18
IV. ETHANOL SUPPLY AND DISTRIBUTION ISSUES	20
A. BIOMASS ETHANOL PRODUCTION POTENTIAL IN THE NORTHEAST	21
B. STATUS OF EFFORTS TO COMMERCIALIZE CELLULOSIC BIOMASS ETHANOL PRODUCTION	23
C. CLIMATE AND LAND-USE IMPACTS OF INCREASED ETHANOL USE IN NORTHEAST	24
V. COST ESTIMATES AND REFINERY MODELING	26
VI. STATUS OF STATE ACTIONS TO REDUCE MTBE USE IN THE NORTHEAST	27
A. STATE OF MAINE	27
B. NEW HAMPSHIRE	28
C. CONNECTICUT	28
D. CALIFORNIA	28
VII. CONCLUSION	29

Air Quality, Fuel Supply and Cost Impacts of MTBE and its Alternatives

August, 1999

The Northeast states are seeking to preserve the air quality benefits achieved under the current RFG program while minimizing the risk posed to the region's potable water resources by MTBE. This technical white paper seeks to identify fuel options available to the Northeast states that achieve both these environmental goals at a reasonable cost to consumers. The following conclusions were drawn from this assessment:

1. The RFG program has provided substantial air quality benefits to the Northeast, and those benefits are expected to increase when Phase II of the program is implemented in January 1, 2000 in participating states.
 - In practice, refineries that supply gasoline to the Northeast have overcomplied by 75% with the minimum air toxics requirements of the Phase II RFG program (a 35% reduction compared to a legal minimum 20% reduction). Refineries have also overcomplied with the conventional gasoline performance standard, which requires no change from 1990 levels. Specifically, toxic emissions from conventional gasoline sold in the Northeast have declined by 13% since 1990.
 - Ambient monitoring data collected before and after the implementation of the RFG program supports the conclusion that the presence of RFG helped reduce levels of CO, total toxics, and benzene emissions in the Northeast.
 - Despite reductions in mobile source air toxics in the last several years, ambient levels of these air toxics continue to far exceed health-based risk standards in the Northeast. These unhealthful ambient levels are predicted to increase if MTBE is phased down or banned without additional regulatory steps to secure the current air toxics emissions performance of RFG.
2. The use of oxygenates, such as MTBE and ethanol, contributes to reductions in carbon monoxide and air toxic emissions from motor vehicles through dilution and replacement of toxic gasoline constituents that are high in octane.
 - EPA estimates that the CO benefits of oxygenates in motor fuels will decline as the existing motor vehicle fleet is replaced with newer model vehicles, but that oxygenates will still provide significant benefits until 2005, especially for CO nonattainment areas participating in the winter oxygenate program.
 - Refineries are likely to increase the level of toxic fuel components if levels of MTBE are reduced. In recent months, US EPA and the Colorado School of Mines performed separate statistical analyses on fuel properties from hundreds of samples of real world gasolines produced and sold in 1998. These analyses demonstrate that refiners operate in a predictable fashion in order to achieve economically viable fuels that comply with environmental performance standards. Importantly, a strong correlation was identified: when oxygen content decreased,

refiners typically responded by increasing levels of aromatics, benzene, and olefins.

- There are three likely replacements for MTBE: ethanol, aromatics and alkylates. Octane rates are as follows: MTBE has 110 octane; ethanol has 113 octane; aromatics have 100 octane; alkylate provides 94 to 98 octane. Average octane for the gasoline pool is 88-89. However, in practice, aromatics are the only high octane compound readily available in the northeast to replace the volume and octane loss resulting from an MTBE phase down.
 - In May 1999, the state of Maine instituted a 7.9 RVP¹ gasoline instead of federal RFG. The fuel properties reported by Maine's gasoline suppliers and distributors show a decrease in MTBE use by half and a significant increase in aromatics by 20%. In addition, all premium grade gasolines contained substantially more aromatics than regular grade.
3. Ethanol is the most likely oxygenate to replace MTBE. It will take several years to develop an adequate supply and distribution infrastructure in the Northeast. Moreover, several significant air quality issues need to be addressed before Northeast states pursue policies that result increased use of ethanol.
- Combustion of ethanol-blend gasoline results in substantial (70%) increases of acetaldehyde emissions. Ambient levels of acetaldehyde are presently far in excess of health-based risk standards in the Northeast.
 - Refineries are likely to use ethanol at 10% by volume in conventional gasoline to take advantage of the statutory one pound RVP waiver, which would lead to a substantial increase in VOC emissions. NESCAUM recommends elimination of this RVP waiver for ethanol.
 - Ethanol's higher oxygen content allows refiners to meet the 2% by weight oxygen requirement with only 5.7% by volume ethanol, which leaves aromatics/alkylate to satisfy the remaining octane need.
 - Even a small amount of ethanol in gasoline raises its fuel volatility by about one pound per square inch. As a result of this unique characteristic, blending or commingling ethanol-based and nonethanol-based gasolines increases the RVP of the combined gasoline in the fuel tank, and results in elevated evaporative emissions of VOCs.
 - Ethanol receives a federal tax credit of 54 cents per gallon, which reduces the revenue in the highway trust fund.
 - Biomass ethanol has the potential in the Northeast for reducing CO₂ emissions, eliminating the need for waste disposal, and retaining 120 million dollars a year in the Northeast economy. However, no commercial plant currently exists in the Northeast to manufacture biomass ethanol.

¹ RVP is an acronym for Reid vapor pressure, which is a measure of fuel volatility. Higher RVP means greater fuel volatility and increased evaporative emissions of volatile organic compounds, or VOCs. Low RVP is especially important in the warmer, summer months when evaporation is a greater concern than in the winter.

4. There are two likely non-oxygenate alternatives to MTBE: aromatics and alkylate. The use of aromatics to replace MTBE is likely to substantially increase toxic emissions from motor vehicles operated on RFG and conventional gasoline, or CG. The health effects of alkylate is not well understood, and a rigorous evaluation of the potency, combustion by-products and environmental fate and transport should be conducted prior to increasing its use in gasoline.
 - Aromatics are produced by the reformer unit at refineries, and are a good source of octane. Aromatics is a term for a group of gasoline constituents such as benzene, toluene and xylene, which pose risks to water resources and contribute to emissions of benzene when combusted in motor vehicles.
 - Aromatics are widely used in gasoline to increase octane. In the Northeast, ambient levels of benzene, a known human carcinogen, far exceed health-based risk standards.
 - Alkylate provides octane without apparent increases in toxic emissions, and may not pose a risk to water resources. However, due to these attractive features, alkylate is already in short supply. Moreover, little data is available on the health and environmental impacts of increasing the use of alkylate in gasoline. Given the history of MTBE, it would be prudent to examine alkylate carefully prior to substantially increasing its use in gasoline.
5. Refinery modeling should be done to better define the costs associated with significantly reducing MTBE over three years while establishing new regulatory requirements to preserve the current air toxics benefits achieved under the existing RFG program.
 - Available refinery modeling cost analyses estimate a 2.5 cent increase in the cost of a gallon of gasoline by shifting from MTBE to ethanol, but these analyses assume that motor vehicle air toxic emissions from RFG sold in the Northeast increase substantially (40%), rising to the minimum toxics performance standard allowed by law.
 - Experts estimate that three years or more are necessary to shift away from use of MTBE in gasoline without causing price spikes or market disruptions. The desire to achieve substantial reductions in MTBE, coupled with potential legal constraints and concerns about the near-term viability of alternatives to MTBE, has led some states to opt out of the RFG program. To date, the states that have opted out of the RFG program have done so without economic hardship, but the gasoline sold in these states does not provide the air quality benefits of the RFG program.

I. Introduction

The Northeast states are seeking to preserve the air quality benefits achieved under the current RFG program while minimizing the risk posed to the region's potable water resources by MTBE. This technical white paper seeks to identify fuel options available to the Northeast states that achieve both these environmental goals at a reasonable cost to consumers. In its Phase I technical white paper, "An Assessment of Options for Reducing MTBE in Reformulated Gasoline," NESCAUM examined a wide array of alternative fuel options. This Phase II analysis builds upon that previous work, incorporates comments received on the Phase I white paper and new studies and analyses, and adds a new section on biomass ethanol opportunities in the Northeast. In addition, this paper identifies the need for future refinery modeling work as part of Phase III of this effort.

The emissions performance of MTBE-based RFG is best understood in light of the gasoline constituents that refineries may use in place of MTBE. The most likely alternatives to MTBE are ethanol, an oxygenate with high octane, and two widely-used, high-octane gasoline blendstocks called aromatics and alkylate.² NESCAUM is particularly concerned about increases in air toxic emissions because ambient levels of mobile source air toxics already far exceed health-based risk standards in the Northeast (see white paper on health impacts). As will become evident in the discussion that follows, refineries that supply the Northeast have overcomplied with Phase II RFG toxic performance standards by more than 75%, in part due to the presence of MTBE. It is this substantial margin of overcompliance that may be lost if MTBE is reduced or eliminated from RFG. In addition, toxic air emissions from conventional gasoline sold in the Northeast have declined since 1990, and those emissions benefits may also be diminished or lost if MTBE is phased out of RFG.

Refinery modeling by the U.S. Department of Energy (DOE) and the California Energy Commission (CEC) suggests that ethanol would be the primary replacement for MTBE if the latter were phased out of existing clean fuels programs. Regulatory options that result in replacing MTBE with ethanol are estimated to increase the cost of a gallon of gasoline by 2.5 cents. In addition to ethanol, alkylate and aromatics would likely contribute to the replacement of MTBE, depending on the regulatory approach taken. However, the DOE cost per gallon estimates assume that refineries will only meet the minimum regulatory requirements for toxic air emissions, which will, in effect, result in a 40% increase in toxic air emissions in the Northeast. The DOE cost estimates mentioned to provide policy makers with a frame of reference, but it must be understood that additional refinery and economic modeling must be completed in order to assess the cost of preserving the air toxic reductions currently achieved under MTBE-based RFG.³

² Alkylate is a gasoline blendstock produced by reacting isobutane with olefins. It consists of branched-chain paraffins, has very low aromatics content and no sulfur or olefins. It has relatively high octane typically ranging from 94 to 98.

³ NESCAUM strongly recommends additional refinery modeling to estimate the costs associated with a phase down of MTBE while preserving current levels of air toxic reductions in the RFG and conventional gasoline pools.

This paper is divided into three main sections. The first provides background and context about the Federal Reformulated Gasoline (RFG) program and the role of MTBE. The second provides information on Northeast demand for RFG and MTBE, the availability of MTBE-alternatives, and the potential for biomass ethanol production in the Northeast. The third section of this paper recommends additional technical and economic modeling to better estimate the impact of changing the MTBE content in Northeast gasoline while maintaining current levels of environmental performance in the RFG and conventional gasoline pools. It also summarizes state action on MTBE in the Northeast to date. (Note that more details on the health, water quality, and remediation issues relevant to the current MTBE debate are provided in separate NESCAUM white papers.)

II. Background and Context

A. What is Reformulated Gasoline?

The current federal RFG program is mandated by §211 of the 1990 Clean Air Act Amendments. Its purpose is to reduce motor vehicle emissions of smog-forming pollutants such as volatile organic compounds (VOCs) and nitrogen oxides (NOx) as well as certain toxic or hazardous air pollutant (HAP) emissions.⁴ The Act requires EPA to promulgate regulations which “shall require the greatest reduction in emissions of ozone forming compounds (during the high ozone season) and emissions of toxic air pollutants (during the entire year) achievable through the reformulation of conventional gasoline, taking into consideration the cost of achieving such emission reductions, any nonair-quality and other air-quality related health and environmental impacts and energy requirements.” In addition, the Act stipulates that RFG must be sold in the nine most polluted ozone non-attainment areas, which at present include greater Connecticut⁵ and the New York City and Philadelphia metropolitan areas.⁶ Other areas of the Northeast are currently participating in the federal RFG program on a voluntary opt-in basis.

The federal RFG program was to be implemented in two phases: Phase I was implemented in 1995 and Phase II goes into effect in 2000. At present, the federal RFG program employs two types of regulatory requirements: emissions performance standards and fuel specifications. By contrast, California’s clean fuels program was initially designed with specific fuels formulations. However, in 1995, California adopted the “Predictive Model” to evaluate alternative fuel formulations. Refineries may choose to use the Predictive Model to demonstrate compliance with emissions standards for NOx, hydrocarbons, and potency-weighted toxics. The Predictive Model cannot be used to replace per gallon caps, such as summer RVP. Both types of requirements are summarized in Table 1.

4 The current program represents a compromise from more ambitious fuels programs that were under discussion in the Congressional debate leading up to the 1990 Amendments. EPA had been given authority to ensure that fuels and fuel additives did not endanger public health or impair vehicle emission control systems as early as 1970. However, not until 1990 was the regulation of fuels explicitly mandated as a means of achieving pollutant emissions reductions.

5 Including Hartford, New Britain, Middletown, New Haven, Meriden, and Waterbury.

6 The New York City area includes parts of Connecticut and northern New Jersey; the Philadelphia area includes Trenton and other parts of southern New Jersey.

Table 1
Federal and California RFG:
Performance Standards and Fuel Specifications

	Phase I RFG (1995-1999)	Phase II RFG (2000 and beyond)	California Phase 2 RFG ⁷
Performance Standards			
• VOCs	17.1%	27.4%	--
• NOx	1.5%	6.8% (summer only)	--
• Toxics (mass emissions)	16.5%	21.5%	--
Fuel Specifications (per gallon)			
• Oxygen Content (by weight)	2.0% to 3.5%	2.0% to 3.5%	A 2.7% cap, with no average limit
• Sulfur (ppm)	--	--	30 average with 80 cap.
• RVP, psi	--	--	7.0 cap (summer only)
• T50, F	--	--	220
• T90, F	--	--	330
• Aromatics vol.%	-	--	22 average, with a 30 cap
• Olefins vol.%	--	--	4.0 average with a 10 cap
• Benzene vol.%	1.0	1.0	0.80 average with a 1.20 cap

The RFG performance standards shown in Table 1 represent the minimum percentage emissions reductions that must be achieved by vehicles operating on RFG compared to vehicles operating on 1990 conventional gasoline. The use of such standards, rather than detailed fuel specifications, was intended to give fuel refiners compliance flexibility and to reduce costs. The emissions reductions associated with RFG are significant, especially for VOCs and toxics.⁸

Preliminary analysis of ambient VOC data collected at Photochemical Assessment Monitoring Station (PAM) sites located in RFG areas found statistically significant changes at some sites consistent with RFG introduction in 1995. Comparing 1994 to 1995 data, significant decreases in ambient benzene median weight percent and benzene ratios were detected at a number of sites.⁹ Available gasoline property data verifies that the benzene content of gasoline sold in these RFG areas decreased between 1994 and 1995. Ambient levels of certain aromatic species such as some aromatics (e.g., xylene)

⁷ California Code of Regulations, Title 13, sections 2262.1 to 2262.7.

⁸ Compliance with RFG performance standards is determined by entering the gasoline fuel parameters into the EPA Complex Model, which provides an estimate of the emissions from a motor vehicle operated on various blends of gasoline.

⁹ As used in this study by Sonoma, ambient benzene mean weight percent is benzene levels compared to total NMHC. Benzene ratios are benzene levels compared to toluene levels and benzene levels to acetylene levels.

also showed significant declines at a number of monitoring sites in RFG areas (Sonoma, 1998).

In practice, the federal RFG program has produced even greater than anticipated air quality benefits. Table 2 shows the reductions in VOCs, NO_x, and toxics emissions that have been achieved by Phase I RFG compared to the Phase I and II emissions performance standards.¹⁰ Overcompliance has been especially dramatic with respect to toxics, where actual emissions reductions of 35% have been achieved in the Northeast in 1998, though the applicable performance standard requires only a 16.5% reduction (see Table 2).

Recognition of the substantial *overcompliance* being achieved by the existing RFG program is critical to an examination of program alternatives. Therefore, when analyzing options that, “maintain” the air quality benefits of the current program, it is important to be explicit about whether the statutory minimum reductions are being maintained or whether actual performance is being maintained. Because actual RFG performance already exceeds Phase II toxics requirements, it is possible that future changes to the composition of RFG could result in an *increase* in toxic emissions while still complying with Phase II requirements.

Table 2
Emissions Reductions from Federal RFG in the Northeast States

Pollutants	Phase I RFG (1995 – 1999)			Phase II RFG (2000+)
	Performance Standards	Actual Reductions (1997) ¹¹	Actual Reductions (1998) ¹²	Performance Standards
VOCs	17.1%	18%	21%	27.4%
NO_x	1.5%	3%	5%	6.8%
Toxics (mass emissions)	16.5%	30%	35%	21.5%

Northeast states’ implementation plans to meet national ambient air quality standards for ozone smog now rely heavily on emissions reductions achieved through participation in the federal RFG program. If states were to abandon clean fuels programs altogether (as represented by Option 4), substantial emissions reductions would be required from other programs and source sectors to maintain states’ progress toward key air quality objectives.

It should also be noted that although many areas of the Northeast are now participating in the federal RFG program on a voluntary opt-in basis, they might be constrained from

10 See Relative Cancer Risk of Reformulated Gasoline and Conventional Gasoline Sold in the Northeast, NESCAUM, August, 1998, at pages 17-19, Table III-4, 5, and 6, and accompanying text for information on how these emissions reductions were calculated and their underlying gasoline fuel parameters.

11 Id.

12 National Blue Ribbon Panel on Oxygenates in Gasoline, Final Report, August 1999.

opting out of the program at any time they choose. Under an EPA rulemaking designed to give refiners investment certainty about future demand for RFG, states that did not exercise the option to opt out of Phase I RFG by the end of 1997 are required to stay in the program until at least January 1, 2004. Among NESCAUM states, only Maine has satisfied the 1997 opt out requirement.¹³ The implications of this requirement are revisited in the discussion of regulatory options below.

B. The Role of MTBE in Reformulated Gasoline

1. Carbon Monoxide Benefits of Oxygenates

As noted previously, the federal RFG program specifies minimum oxygen content of 2% by weight.¹⁴ The presence of oxygenate fosters more complete fuel combustion in the engine and was originally mandated in past federal fuel regulations as a means of reducing carbon monoxide (CO) emissions. MTBE has been widely used to meet the oxygenate requirements of the federal RFG program and as an octane enhancer and is now present in some 70% of all gasoline sold in the U.S.

MTBE is manufactured by the chemical reaction of methanol and isobutylene. Methanol (methyl alcohol or wood alcohol) is typically manufactured from natural gas and is highly toxic. The finished ether does not contain methanol. Isobutylene is a petrochemical that is formed in the refinery process. MTBE and ethers have a very distinct odor and taste similar to turpentine.

The federal reformulated gasoline program requires all compliant gasolines to contain oxygen content of 2% by weight. The RFG program does not require refineries to use MTBE or any other oxygenate. One purpose of the oxygen requirement was primarily to reduce emissions of carbon monoxide. Ambient levels of carbon monoxide are usually more pronounced in the winter months because cooler temperatures cause air pollution to remain close to ground, while in the summertime, the sun warms the ground more quickly and earlier in the day, causing upward air currents that lift ambient levels of CO into the atmosphere. Cooler temperatures also lead to higher emissions of carbon monoxide from mobile sources, especially during startup. For these reasons, states with CO nonattainment areas may still be interested in maintaining winter oxygenate programs, or their equivalent.

While increasing the oxygen content of gasoline is still a useful CO reduction strategy, the CO benefits of oxygenated fuels have declined since the introduction of vehicles with electronic air/fuel ratio controls in the early 1990s.¹⁵ EPA estimates through Mobile 6 – a draft of the most up-to-date version of the mobile model that includes early 1990 vehicles -- that CO emissions resulting from the use of oxygenates will decline as older vehicles are replaced with newer vehicles. Specifically, the use of MTBE at 11% by volume will

¹³ See 62 Fed. Reg. 54552 (October 20, 1997).

¹⁴ Oxygen weight to volume ratios vary from oxygenate to oxygenate. For MTBE, the 2% weight requirement translates into an 11% volume requirement. For ethanol, the 2% weight requirement translates into a 5.7 volume percent requirement due to ethanol's higher oxygen content.

¹⁵ Auto/Oil.

achieve CO reductions of about 6% in 2000, and decline to about 3% in 2005. For a winter oxygenate program that uses oxygenates at 3.5% by weight, the CO benefits increase in a linear fashion.¹⁶

2. The Role of MTBE in Reducing Mobile Source Air Toxic Emissions

MTBE and other oxygenates also function as octane enhancers and in this capacity provide important collateral toxic emissions benefits. MTBE's toxic benefits are a result of dilution and replacement of more toxic octane enhancers such as aromatics and olefins. Aromatics are a group of chemical compounds such as benzene and toluene that are widely used by refiners to improve octane in gasoline blends. When combusted, aromatics contribute to motor vehicle exhaust and evaporative benzene emissions. Olefins are also a good source of octane, and contribute to motor vehicle exhaust emissions of 1,3-butadiene. The cancer potency of 1,3-butadiene is more than three times that of benzene, and both are known human carcinogens.

In order to better understand the relationship between oxygen content in gasoline and levels of aromatics and olefins, EPA gathered data on gasoline fuel properties from a statistical sampling of retail gas stations in RFG cities, and from RFG batch reporting data from RFG producers and importers.¹⁷ The Colorado School of Mines independently analyzed this dataset. The total dataset contains roughly 19,000 observations from summer and winter, regular, mid-grade and premium. These two statistical analyses of fuel properties from thousands of samples of real world gasolines demonstrate that refiners operate in a predictable fashion in order to achieve economically viable fuels that comply with environmental performance standards. Importantly, decreases in oxygen content have resulted in significant increases in the content of aromatics, benzene, and olefins.

Both analyses found an inverse relationship between MTBE and other octane sources.¹⁸ The results from the Colorado School of Mines analysis are summarized in Table 3, "Regression Analysis of EPA RFG Survey Data, 1998 Summer Gasoline, Regular Grade." Correlations for each fuel parameter achieved a 95% confidence level or greater. The analysis revealed surprisingly strong relationships between oxygenates and other gasoline octane compounds. A negative coefficient indicates an inverse relationship between a change in oxygen and the fuel parameter. Using benzene as an example, if oxygen content were to increase, benzene content would decline, assuming that all other gasoline properties are held constant. The same inverse relationship holds true for aromatics and olefins. In contrast, direct relationship is found between oxygen content and RVP. The inverse relationship between oxygen content and aromatics and olefins is not seen in premium grades. This suggests that the high octane requirements of premium fuel cannot be satisfied without blending both oxygenates and aromatics. The parameters

16 National Blue Ribbon Panel on Oxygenates in Gasoline, Final Report, August 1999.

17 Air Toxics and Oxygen Data, 1998 RFG Surveys, EPA Presentation to Blue Ribbon Panel on MTBE, July 1999.

18 Graboski, Michael S., Preliminary Regression Analysis of EPA RFG Survey Data, 1998 Summer Gasoline, Colorado School of Mines, August 1999.

for aromatic and olefin changes in regular grade are much larger than would be expected due to dilution.

Table 3
Regression Analysis of EPA RFG Survey Data
1998 Summer Gasoline, Regular Grade

Fuel Parameters	Coefficients
Benzene	-0.034
RVP	0.0236
Aromatics	-0.0138
Olefins	-0.0175
Sulfur	-0.0002
E200	0.00627
E300	-0.019

Increases in aromatics, benzene and olefins will cause significant increases in motor vehicle air toxic emissions of benzene and 1,3-butadiene.¹⁹ As described in detail in the technical white paper on health effects of MTBE, current ambient levels of motor vehicle air toxics such as benzene, 1,3-butadiene, acetaldehyde, and formaldehyde are already far in excess of health-based risk standards in the Northeast.

The recent experience of the state of Maine provides additional support for the inverse relationship between oxygen content and aromatics. Maine opted out of the RFG program in 1999, and required fuel suppliers and distributors to produce 7.9 RVP fuel starting on May 1, 1999. In effect, the state lifted the oxygen mandate while leaving market forces to dictate the amount of MTBE in Maine gasoline. The new state fuel volatility regulation also requires refiners and fuel suppliers to report on fuel properties of gasoline delivered to Maine if requested by the state. Table 4 shows the fuel properties received by Maine in May 1999, and baseline fuel properties from two samples collected prior to the change in fuel requirements.

Table 4
Maine Preliminary RVP 7.2 Fuels Data for May 1999

	RVP	MTBE	Benzene	Aromatics	Sulfur	Olefins
Maine Fuel (5/99)	7.9	0.09	0.66	32.7	148	6.9
Maine RFG (Portland, 1998)*	7.8	2.18	0.071	26.1	170	7.8

*Only two samples

¹⁹ Specifically, the complex model estimates a change in toxic emission reductions from 27% to 12%, which is a 55% increase in toxic air emissions.

The Maine fuel shows a decline in MTBE levels of more than 50%, and a corresponding increase in aromatics of 20% compared to 1998 Portland fuel samples. While this comparative baseline is not ideal, this does provide anecdotal evidence that as oxygen content decreases, aromatics tend to increase, perhaps substantially. Maine's olefin and benzene levels stayed relatively constant. The four premium grade gasoline blends with 93 octane contained the highest levels of aromatics ranging from 37 to 53.7% by volume (see Appendix B for a complete list of fuel properties). This is not surprising since an increase in four octane points will typically require a substantial increase in octane boosters such as aromatics and oxygenates. This data shows that refiners prefer aromatics to MTBE when regulatory constraints are not present.

The California Air Resources Board recently published a draft proposal for public comments on specifications for California Phase 3 Reformulated Gasoline. The draft proposal introduces possible changes to specifications in four of the eight fuel parameters. Sulfur, benzene and RVP are further reduced, while aromatics are allowed to increase from a cap of 30% by volume to 35% by volume. California has acted to phase out of the use of MTBE in gasoline sold in the state over three years, and this upward change in aromatics was apparently necessary to allow refiners to replace the lost octane resulting from the phase out of MTBE with aromatics.

The change in gasoline fuel properties in Maine, along with the proposed change in fuel specifications for Phase 3 California RFG, is consistent with the trends identified in the EPA/Colorado School of Mines statistical analyses of 1998 gasoline samples. All these data points support the conclusion that when oxygen content decreases, refiners may be expected to react by increasing levels of aromatics and olefins. It should be noted that the use of historic data that varies oxygen content between 1.7% and 2.3% by weight in a gasoline pool replete with MTBE may underestimate the necessary increase in aromatics if oxygen content and available octane are reduced far more substantially due to a phase down of MTBE. Additional analysis of this dataset of 1998 RFG fuel samples should be conducted to better quantify this relationship.

3. Reductions in Mobile Source Air Toxic Emissions from Conventional Gasoline in RFG Areas

Toxic air emissions from conventional gasoline sold in the Northeast have declined by 13% since 1990.²⁰ The RFG program's anti-backsliding provisions will not safeguard these reductions. Faced with a shortage of low-toxic, high-octane blendstocks in the absence of MTBE, refineries may choose to shift aromatics and olefins into the CG pool, thus increasing air toxic emissions from vehicles operated on CG while still complying with the antibacksliding provisions of the Act. The emissions benefits gained since 1990 in the CG pool may be diminished or lost if MTBE is phased out of RFG.

20 NESCAUM, Relative Cancer Risk of Reformulated Gasoline and Conventional Gasoline Sold in the Northeast, August 1998.

C. Oxygenate Alternatives to MTBE

Generally speaking, oxygenates fall into two chemical categories: ethers and alcohols. MTBE is the leading ether-based oxygenate. Other ether-based oxygenates are ethyl tertiary butyl ether (ETBE) and tert amyl methyl ether (TAME). ETBE is manufactured by reacting ethanol and isobutylene; TAME by reacting methanol and isoamylene. Unfortunately, there is little scientific information or field data on the behavior of ETBE or TAME when leaked or spilled. However, all ethers, due to their chemical composition, are expected to behave similarly when released into the environment. They are all highly soluble in water and resistant to biodegradation; as a result their presence in the environment is difficult to remediate.²¹ Because water contamination is the principal concern driving the current reassessment of MTBE's role in the RFG program, ETBE and TAME are not considered viable alternatives at this time. Until data are available demonstrating that these ethers behave differently than MTBE, it is appropriate to assume that they present similar environmental liabilities. Hence, the regulatory options for reducing MTBE use that are examined later in this paper are expressed broadly as limits on all ethers.

1. Ethanol

The chief alcohol-based oxygenate alternative to MTBE is ethanol (ethyl alcohol or grain alcohol). In the United States, ethanol is produced by the fermentation of agricultural products, primarily corn. It is the same alcohol used in beverage alcohol but meeting fuel grade standards. The ethanol used in gasoline is denatured to make it unfit for drinking. Ethanol's octane rating is 113 and will increase octane 2.5 to 3.0 numbers at 10% concentration in gasoline.

Though highly soluble in water, ethanol biodegrades readily, is not considered toxic, and does not present taste and odor issues when present in water. Like MTBE, ethanol also functions as an octane enhancer and can therefore displace other, more toxic octane boosting blendstocks. It is widely considered the most viable near-term alternative to MTBE, largely because it is the only oxygenate that could be produced in quantities capable of supplanting a substantial portion of the MTBE market in the next three years.

An important drawback to the use of ethanol from an emissions perspective is its impact on the evaporative properties of gasoline. Small amounts of ethanol raise the volatility of gasoline (as measured by Reid vapor pressure or RVP) by about 1 pound per square inch (psi). Higher RVP implies increased evaporative emissions of VOCs and toxics such as benzene. To meet the VOC reduction requirements of Phase II of the RFG program, it is estimated that RVP will need to be limited to 6.5 to 6.7 psi. To reach that level with an ethanol blend, a base gasoline with an RVP of 5.5 to 5.7 psi may be needed. Some

²¹ Odor and taste thresholds for ether-based oxygenates range from 20 to 40 parts per billion (ppb) for MTBE, to about 50 ppb for ETBE and about 200 ppb for TAME. Interagency Assessment of Oxygenated Fuels, National Science and Technology Council, Committee on Environment and Natural Resources, June 1997 (2-24).

refiners assert that they cannot produce a 5.5 to 5.7 psi volatility blendstock at a reasonable cost.²²

Moreover, even if such a blendstock were used, the inadvertent blending of ethanol-containing and ethanol-free gasolines in vehicle fuel tanks could result in unanticipated evaporative emissions increases.²³ This mixing of ethanol and non-ethanol based gasolines in vehicle fuel tanks is called commingling. Even small amounts of ethanol in gasoline raises the fuel volatility by up to one pound psi. As a result of this unique characteristic, blending or commingling ethanol and nonethanol based gasolines increases the RVP of the combined gasoline in the fuel tank, and results in elevated evaporative emissions of VOCs. It is possible to diminish the likelihood of commingling through a seasonal separation of ethanol-based fuels and non-ethanol based fuels. For example, ethanol-based fuels might be used only during the wintertime when evaporative emissions are less pronounced due to colder weather. Ethanol should not be used in the summer ozone season until concerns about RVP and increased evaporative VOCs are resolved. Some state air regulators are concerned that ethanol-based gasoline sold in the winter months will raised RVP and increase CO emissions in CO nonattainment areas. This issue should be carefully considered before a seasonal separation of fuels is proposed.

The Energy and Environmental Research Center at the University of North Dakota recently measured the Reid vapor pressure (RVP) of a series of gasoline-E10 blends to determine the effect on volatility of mixing or “commingling” a nonethanol gasoline with E10.²⁴ The unpublished analysis confirmed that commingling does increase RVP and evaporative hydrocarbon emissions. The ethanol RVP increase was most pronounced in blends of 5% to 35% E-10 and less pronounced once the gasoline blends exceeded a 50% E-10 mixture. Gasoline with 2% ethanol, or a mixture of 80% gasoline with 20% E-10, showed an RVP increases of 0.66 to 0.93 psi over the base fuel RVP. According to the Complex Model, for a typical summertime fuel in the Northeast an RVP increase of 0.93 psi will result in a 14% increase in VOCs, primarily from increased evaporative hydrocarbon emissions. In the DOE refinery modeling runs used to illustrate the cost impacts for some of NESCAUM’s regulatory options, DOE assumed that refineries would split their RFG and CG pools into ethanol and nonethanol blends in order to minimize expenses. If refineries are only permitted to use ethanol blends to prevent

22 For instance, Midwest refiners serving the Chicago area have decided to switch from ethanol to MTBE to meet the RFG oxygenate requirement for the summer months because the additional VOC reduction requirements in Phase II of the program effectively prohibits their use of ethanol.

23 To complicate matters further, this problem might not be resolvable by lowering the volatility of all gasoline. In cool climates especially, vehicles may have difficulty functioning on gasoline with an RVP of just 5.5 psi. In this context, the only option for ensuring against unintended evaporative emissions increases may be to require ethanol use everywhere, blended into a sufficiently low volatility blendstock. As will be discussed later, there are several obstacles to the use of ethanol in all gasolines.

24 Addition of Nonethanol Gasoline to E10 – Effect on Volatility, Ted Aulich, John Richter, University of North Dakota Energy & Environmental Research Center, July, 1999. This analysis used gasolines with relatively high RVPs (9.85 and 9.9) compared with Northeast typical summertime RVP’s of 7.7 to 7.9, which are expected to decrease to about 6.5 to 6.7 psi in order to achieve Phase II VOC reductions of 25% in 2000. NESCAUM recommends additional study to determine the impact of commingling of gasoline blends with lower RVPs.

commingling problems, it is likely that costs will increase (see Appendix A attached to the Phase I White Paper, “An Assessment of Options for Reducing MTBE in Reformulated Gasoline”).

Aside from ethanol, the only other alcohol alternative to MTBE is tertiary-butyl alcohol (TBA), an MTBE metabolite. However, TBA is not considered a viable alternative because of limited supplies coupled with evidence that it may be carcinogenic. TBA production capacity is very limited and would not be adequate to supply existing oxygenate requirements, even for the Northeast RFG market alone.

While ethanol has a very high octane rating, its high oxygen content hampers its value as an octane enhancer. The octane ratings of commonly used octane enhancers are as follows: MTBE (110); ethanol (113); toluene (103); xylene (106); benzene (101); alkylate (94-98). Refiners need only use 5.7 vol.% ethanol to meet the 2.0wte% oxygen requirement. Compared to MTBE at 11% by volume, ethanol at 5.7% by volume is significantly less effective at displacing and diluting other toxic, octane-enhancing gasoline constituents. While ethanol’s dilution/displacement effect does help to reduce toxic emissions, ethanol also leads to increases in VOCs and toxic evaporative emissions from conventional gasoline due to one-pound RVP waiver, and through commingling between ethanol and non-ethanol gasoline blends in the gas tank. Absent the oxygen requirements and the toxic mass performance standards of the federal RFG program, refiners might rely to a greater extent on more toxic octane enhancers such as benzene, aromatics, and olefins.

D. Non-Oxygenate MTBE Alternatives

As noted previously, there are a number of octane boosting, non-oxygenate alternatives to MTBE. These additives present viable options only in the absence of the current oxygenate mandate. Thus, they are available only to areas of the Northeast that are currently participating in the federal RFG program on a voluntary basis.²⁵ As discussed earlier, many of these alternatives are significantly more toxic than MTBE and will cause increases in mobile source air toxic pollutants that are already exceeding ambient health-based risk standards.

Due to their relatively low toxicity, the two primary *non-oxygenate* alternatives to MTBE are alkylate and aromatics, primarily toluene.²⁶ Alkylate is produced in a refinery’s alkylation unit, which results in an alkylate product that contains no olefins and has a high octane rating. Alkylate is believed to produce relatively little motor vehicle exhaust emissions of hazardous air pollutants. For these reasons, it is a very valuable gasoline blendstock. At present, alkylate production at East Coast and Gulf Coast refineries is close to capacity. Hence, it will take some number of years for refineries to build or

25 In mandatory opt-in areas (i.e. parts of Connecticut and the greater New York City and Philadelphia metropolitan areas), a change in federal statute would be required before non-oxygenate octane enhancers could be used in place of MTBE.

26 Two other aromatic compounds -- benzene and xylene -- are minor constituents of gasoline, and increased levels of either compound would have serious environmental impacts. Benzene is a known human carcinogen. Xylene is highly photochemical reactive and a major contributor to smog formation.

modify facilities that are then capable of replacing the volume and octane lost if MTBE is phased out of gasoline. Toluene is an aromatic compound and, while associated with some toxic by-products, is less toxic than benzene. Toluene is the most common hydrocarbon purchased for use in increasing octane. Production capacity may currently exist to produce sufficient toluene to replace MTBE by volume. (The health implications of these alternatives are considered in a separate NESCAUM white paper.)

As summarized in Table 5, MTBE and ethanol are significant sources of octane: MTBE has 110 octane; ethanol has 113 octane. Average octane for the gasoline pool is 88-89. On average, aromatics provide about 100 to 106 octane. When produced in the refinery, aromatics are primarily found in reformate, a gasoline feedstock. Reformate makes up about 33% by volume of PADD I RFG blendstocks, according to DOE modeling. Ethanol contains comparable octane to MTBE, but ethanol's higher oxygen content allows refiners to meet RFG's 2% by weight oxygen requirement with only 5.7% by volume ethanol, which leaves aromatics/alkylate to satisfy the remaining octane need. Without ethanol, the expected use of aromatics/ alkylate is significantly greater.

Table 5
Economic and Public Health Information Related to MTBE
and Its Alternative Gasoline Constituents

Gasoline Octane Enhancers	Octane Rating	Dollar per gallon (3/99)	Typical Amount in RFG (Northeast)	Toxic Air Pollutant Increases	Cancer Potency Relative to Benzene	Risk to Water Resources
MTBE	110	0.53	11%	MTBE*/ Formaldehyde	0.14 / 0.004	High
Ethanol	113	1.04**	5.7%	Acetaldehyde	0.07	Low
Toluene / Xylene	103 / 106	0.52	17 - 21%	Benzene -- exhaust	1.0	Moderate
Benzene	101	0.69	0.6 – 0.7%	Benzene -- evaporative & exhaust	1.0	High
Olefins		no market price	7 - 15%	1,3-butadiene	3.58 to 33	Low
Alkylate	94-98	no market price	5-10%	--	--	Low

*MTBE is not considered a human carcinogen. However, in order to provide an adequate margin of safety for public health and the environment, NESCAUM assumes for the purposes of this analysis that MTBE is a relatively weak carcinogen.

** Does not include the federal subsidy of 54 cents per gallon.

Most of the octane additives listed in Table 5 correspond to increased emissions of certain toxic air pollutants. The use of MTBE results in increased emissions of MTBE, primarily from evaporation, and formaldehyde in exhaust emissions. The cancer potency of these two air toxics is relatively low with compared with benzene and 1,3-butadiene. However, MTBE is rated as a high risk to the potable use of water resources due to its mobility and persistence in soil and groundwater and its "turpentine-like taste and odor.

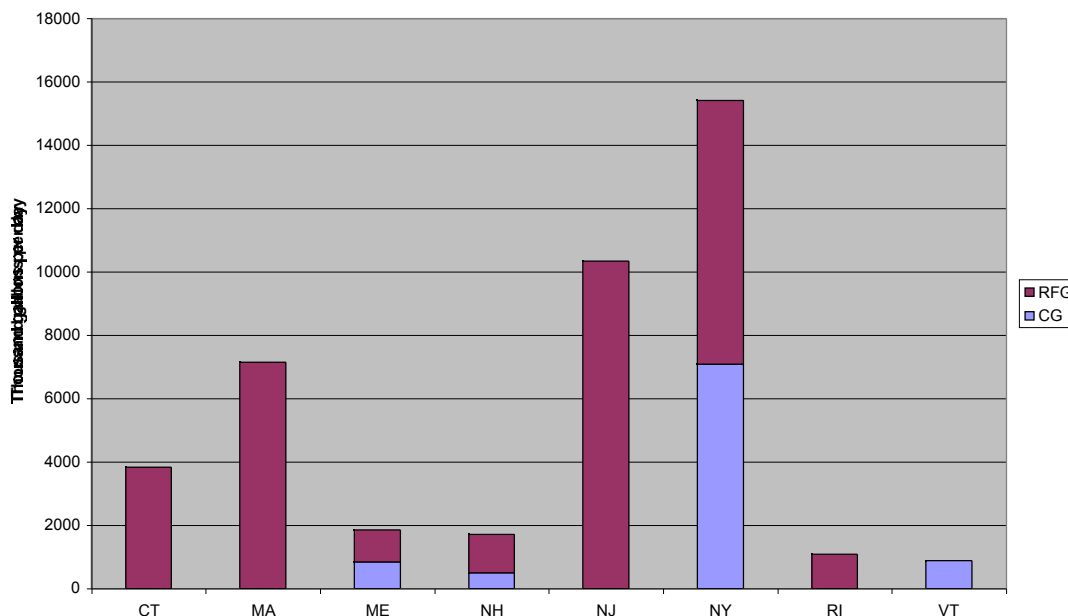
When combusted in a motor vehicle, ethanol-based gasolines show substantial increases in acetaldehyde emissions, but the cancer potency of acetaldehyde is relatively low compared benzene and 1,3-butadiene. Unlike MTBE, ethanol poses only a low risk to potable water resources. Toluene and xylene emit benzene, which has high cancer potency. However, toluene and xylene are not carcinogens, and pose only a moderate risk to water resources.

Benzene is found at only low levels in gasoline, and its market price of 69 cents reflects its value as a petrochemical feedstock. However, the presence of benzene in gasoline results in evaporative and exhaust emissions of benzene, and it poses a high risk to water resources because it is a known human carcinogen. When combusted, olefins result in emissions of 1,3-butadiene, which are 3 to 33 times the cancer potency of benzene. By themselves, olefins pose only a low risk to water resources. Alkylate, based on available information, does not result in toxic emissions nor do they pose a risk to water supplies. However, the health effects of alkylate are not well understood, and a rigorous evaluation of the potency, combustion by-products and environmental fate and transport should be conducted prior to increasing its use in gasoline. Each octane supplement is accompanied with its own set of public health and water resource concerns and questions that must be carefully considered prior to any significant change in gasoline fuel formulations.

III. MTBE Supply and Distribution Issues

At present, MTBE is a significant component of gasoline sold in the Northeast. Seventy-five percent of the gasoline sold in the Northeast is RFG, which typically contains MTBE at 11% by volume. In addition, conventional gasoline, especially the higher-octane grades, typically contains smaller amounts of MTBE.

Figure 1
1997 Reformulated and Conventional Gasoline Consumption in the Northeast



As a region, the Northeast is one of the nation's largest markets for MTBE, consuming approximately 3.6 million gallons per day (mgd) in 1997 and accounting for 43% of national MTBE consumption. Refineries located on the East Coast and Gulf Coast supply most of the gasoline sold in the Northeast. Production of conventional and reformulated gasoline at these refineries is summarized in Table 6, along with estimates of the amount of MTBE used to produce RFG.

Table 6
Refinery Production in September 1998
(million gallons per day)

	Conv. Gasoline	RFG	MTBE Required	MTBE Produced
East Coast	13.4	25.0	2.7	withheld*
Gulf Coast	119.1	27.0	3.0	7.6
Totals	132.4	52.0	5.7	

* Data withheld to protect individual company data.

As Table 6 indicates, the total gasoline production capacity of Gulf Coast refineries is about ten times that of East Coast refineries. However, both regions require roughly

equal amounts of MTBE²⁷ because about 65% of the gasoline produced by East Coast refineries is RFG, compared to less than 19% of the total gasoline produced by Gulf Coast refineries. The smaller role of RFG in Gulf Coast refining allows these refineries more flexibility in complying with changing gasoline regulations and requirements. It is important to note in this context that the modeling analyses discussed in connection with various regulatory options later in this paper are generally limited to East Coast refineries.²⁸

IV. Ethanol Supply and Distribution Issues

Although ethanol is considered the most viable short-term oxygenate alternative to MTBE, widespread use of ethanol – in addition to the drawbacks noted previously – would present a number of significant supply and distribution challenges in the Northeast. At present, the Northeast consumes 31 million gallons per year (0.08 mgd) of ethanol, or about 3% of the total U.S. ethanol market. More than twenty times that amount -- an estimated 684 million gallons per year (1.87 mgd)²⁹ -- would be needed to meet the current oxygen requirement for RFG. Currently, domestic ethanol sales -- at 1.5 billion gallons per year -- are roughly 700,000 gallons per year less than existing capacity. Thus, available capacity should be sufficient to meet the additional demand of replacing MTBE with ethanol in the Northeast market.³⁰ However, if California bans MTBE, as set forth in a recent executive order by California Governor Davis, the combined demand for ethanol could exceed presently available ethanol production capacity.

27 Gulf Coast refineries produce 87% of the MTBE produced nationwide. MTBE production in the United States doubled in the five years from 4.2 million gallons per day in 1992 to 11.3 million gallons per day in 1997 (EIA, Demand and Price Outlook for Phase 2 Reformulated Gasoline, 2000). The East Coast produces only small quantities of MTBE. Source: National Energy Information Center (NEIC). The NEIC's estimate is consistent with information from the US Energy Information Administration (EIA) that estimates about 8,652,000 gallons per day (gpd) in 1998 (EIA-819M Monthly Oxygenate Telephone Report). These data are published in the Weekly Petroleum Status Report and the Petroleum Supply Monthly, Appendix B.

28 One commenter asked for clarification as to why modeling was limited to East Coast refineries (NY DEC). NESCAUM used refinery modeling analysis performed by the Department of Energy for the Blue Ribbon Panel. In order to provide quick turn around time for a significant number of modeling cases, only PADD I was analyzed. Use of PADD I refineries was considered a likely "worst case" scenario since PADD III refineries produce less RFG as a percentage of total production, and thus have greater flexibility in complying with changing circumstances. In the refining industry, greater flexibility typically leads to lower costs.

29 Note that this quantity reflects the smaller volume of ethanol that would be needed, compared to MTBE, to meet the 2% oxygen weight requirement. (See footnote 6)

30 NESCAUM States use 3.6 million gallons per day (mgd) of MTBE at 11% by volume. Ethanol, with its higher oxygen content, is able to attain the 2.0% by weight RFG oxygenate requirement with only 5.7% by volume, or 1.8 mgd. Ethanol excess capacity is 700,000 gallons per year, or about 1.9 mgd. There are some questions as to whether the industry will be able to meet the demand of an additional 1.8 mgd without addition production facilities. In addition, DOE's analysis assumes 10% ethanol content in CG to allow shifting of high-octane, low toxic components in the RFG pool. While not legally required by the mandate, this additional amount of ethanol is necessary for refiners to meet the relatively low cost estimates provided by DOE. About 25% of the Northeast gasoline is CG which will increase ethanol by about 120 million gallons annually for a total of about an 800 million gallons per year.

In addition to near-term supply constraints, there are other possible limitations on the use of ethanol in the Northeast. In particular, pipeline transport of ethanol from the Midwest to the Northeast is likely to be problematic because of ethanol's affinity for water. Water absorbed by ethanol may separate once in a gas tank, causing fuel lines to freeze in the winter and poor engine operation.³¹ As a result, ethanol would either need to be produced in the Northeast or – as is more likely – be transported by rail, truck, or ship.

Finally, there are a number of important issues associated with a substantially increased reliance on ethanol that bear noting here, though they could not be examined in detail within the scope of this analysis. One is that ethanol currently benefits from federal tax subsidies (in the form of a partial exemption from the federal fuel excise tax and an income tax credit) that amount to 54 cents per gallon.³² In addition, a number of states – including Connecticut – offer some sort of ethanol tax incentive.³³ The current, corn-based ethanol industry is dependent on this subsidy; without it, ethanol is substantially more expensive than competing compounds such as MTBE. A large-scale shift to ethanol will have a non-trivial impact on the federal Highway Trust Fund. The effect of reducing federal highway fund resources on the transportation needs of the Northeast states needs to be better understood.

A second issue is that present modes of ethanol production, which rely primarily on corn feedstocks, are relatively resource intensive in terms of both agricultural and energy inputs. As a result, controversy exists about the full fuel-cycle environmental impacts of corn-based ethanol, despite the fact that it is derived from a renewable biomass resource. Recent scientific studies indicate that there is a modest reduction in net carbon emissions from corn-based ethanol relative to petroleum-based conventional gasoline. By contrast, ethanol produced from so-called “cellulosic” (i.e. herbaceous or woody) biomass feedstocks reduces full fuel-cycle carbon emissions nearly 100%, relative to gasoline. Research on producing ethanol from these types of feedstocks and with advanced production methods is presently ongoing and could eventually yield a product that is competitively priced and provides an impressive array of environmental benefits. The potential to make ethanol from alternative biomass feedstocks raises the possibility that the Northeast could eventually develop in-region ethanol resources. In addition, increased use of domestically produced ethanol, to the extent it replaces imported petroleum products, would have the benefit of improving national energy security.

A. Biomass Ethanol Production Potential in the Northeast

The production of ethanol in the Northeast could help to overcome the supply, transportation and distribution hurdles noted above. More importantly, the development of an indigenous energy resource could boost the region's economy, keeping dollars in the Northeast that would otherwise flow to energy producers elsewhere in the country

31 The same phenomenon may cause problems in vehicle engines when the fuel is used.

32 Tax incentives for ethanol were extended to 2007 by the 1998 Transportation Bill. They are due to decline to 53 cents per gallon in 2001, to 52 cents per gallon in 2003, and to 51 cents per gallon in 2005.

33 Connecticut offers a state motor fuel tax exemption for gasohol equivalent to 10 cents per gallon for ethanol.

and overseas. The potential for developing biofuel resources in the Northeast rests on the potential to commercialize ethanol production from feedstocks other than corn, specifically from cellulosic feedstocks such as forestry and mill waste, waste paper, crop residues and dedicated energy crops. This section provides an overview of: (1) the potential for biomass ethanol production in the Northeast, (2) the status of efforts to commercialize cellulosic production processes (including present cost estimates), and (3) current understanding of the environmental and health impacts associated with the increased use and production of biomass ethanol.

1. Potential for Biomass Ethanol Production in the Northeast

This section draws heavily from a 1994 report, commissioned by the Conference of Northeastern Governors (CONEG), concerning *The Potential for Producing Ethanol from Biomass in the Northeast*. The CONEG study examined a variety of possible feedstocks and concluded that the Northeast could support a potentially substantial biofuel production industry -- of a magnitude comparable to that of the existing corn-based industry. Specifically, the CONEG analysis indicates that the quantity of biomass material currently discarded in the NESCAUM states and potentially available from herbaceous and short rotation woody crops could produce more than 1.8 billion gallons of ethanol per year.³⁴

A number of factors affect the actual potential for commercially viable ethanol production from any particular feedstock at any particular site. These include the amount of feedstock available and the degree to which economies of scale can be realized, the cost of feedstocks (and their competing uses), the potential yield from different feedstocks and the complexity of the conversion process, the cost of capital, and a host of site-specific factors including the difficulty of siting and permitting a facility, public acceptance, etc. Based on available quantities and current feedstock costs, the CONEG study concluded that waste paper, paper sludge, and cheese whey were the most likely feedstock candidates for near-term ethanol production in the Northeast. Over the longer term, forestry wood waste also appeared to have high potential as a regional ethanol feedstock. Table 7 below summarizes the chief findings of the CONEG analysis with respect to potential feedstocks for an ethanol industry based in the NESCAUM region. According to these estimates, waste paper alone could support over 400 million gallons per year (gpy) of ethanol production in the region. In the near term, cheese whey and paper sludge could supply an additional 40 million gpy. Over the longer term, forestry wood waste could support an additional 470 million gpy, for a total "high potential" production capacity of 900 million gpy. This amount is equal to approximately two-thirds the output of the existing corn-based industry and slightly in excess of the amount of ethanol estimated to be required in the NESCAUM region (according to DOE refinery modeling) if ethanol is used to replace MTBE in reformulated gasoline.

³⁴ It should be noted that the Northeast region, as defined for purposes of the CONEG study, comprises 11 states, including Pennsylvania, Delaware and Maryland in addition to the NESCAUM states. The results for the NESCAUM region presented below were calculated by subtracting the feedstock estimates for Pennsylvania, Delaware and Maryland from the CONEG estimates and adjusting the resulting estimates of ethanol production potential proportionately.

Table 7
Potential Ethanol Production from Biomass Feedstocks in the NESCAUM Region^(a)

Biomass Type	Quantity Discarded (1000 bone-dry tons/yr)	Representative^(b) Feedstock Cost (per bone-dry ton/yr)	Potential Production (million gpy)	Overall Long-Term Regional Potential	Most Likely for Conversion Soonest
Forestry Wood Waste (hardwood)	4,475	\$30	470	High	Medium
Mill Residue (hardwood)	274	\$7	29	Medium	Medium
Urban Wood Waste^(c)	581	-\$28	61	Low	Medium
Paper Sludge	331	-\$100	32	High	High
Waste Paper	4,154	\$0 to -\$10	415	High	High
Cheese Whey	105	\$125	11	Low	High
Short Rotation Woody Crops	4,107	(d)	411 (e)	Medium	Low
Herbaceous Crops	4,107	(d)	427 (e)	Medium	Low

(a) For the NESCAUM states only; hence figures are lower than the summary results found in the CONEG study.

(b) Represents typical feedstock cost (not including delivery) based on current management options.

(c) For purposes of this study, only used pallets were included.

(d) Data are not available.

(e) Assumes 25% of available Class III cropland and pastureland are available.

B. Status of Efforts to Commercialize Cellulosic Biomass Ethanol Production

The existing commercial ethanol production industry is almost entirely corn-based. It produces approximately 1.4 billion gallons of corn ethanol per year and consumes about 6% of domestic corn production. Corn ethanol is produced through either dry or wet milling processes. Wet milling (which currently accounts for about two-thirds of domestic production) also produces corn oil, corn gluten meal, and corn gluten feed; dry milling produces distillers' grain and solubles (DGS) which is sold as animal feed.

In recent years, considerable research has been devoted to the development of commercially viable ethanol production processes using cellulosic (woody) biomass feedstocks rather than grain feedstocks. Successful commercialization of such processes would greatly expand long-term domestic ethanol production potential by allowing for the use of a greater variety of feedstocks. Moreover, most analysts believe cellulosic ethanol could achieve significantly lower production costs and substantially greater overall environmental benefits. The chief cellulosic processes available at present use either acid hydrolysis or enzyme technology to convert cellulose to sugar for fermentation into ethanol. These processes require substantially less energy input than

current corn-based production. In addition, the unfermentable biomass components – primarily lignin – can be used to cogenerate steam and electricity at the ethanol plant.

Cellulosic ethanol is not yet being produced on a commercial scale, though a few cellulosic plants are currently under construction or in the planning stages. The U.S. Department of Energy's Office of Fuel Development (OFD) estimates that new cellulosic production capacity of over 60 million gpy is currently planned for start-up in the 2001-2003 timeframe. This capacity includes a 10 million gpy facility for producing ethanol from municipal solid waste in New York State. Based on current data and various market assumptions, the costs of commercial-scale cellulosic ethanol production are projected to decline from \$1.40 per gallon in 2000 to less than \$1.00 per gallon in 2010 and less than \$0.80 in 2025, with total production reaching 1 to 2 billion gpy by 2010. Over the long run, government researchers have estimated that the theoretical market supply potential for cellulosic ethanol could be as high as 10 to 30 billion gpy (at feedstock costs in the range of \$30-40 per dry ton).

C. Climate and Land-Use Impacts of Increased Ethanol Use in Northeast

This section summarizes available data on the environmental and health impacts of ethanol, including (1) global warming, energy, and land use impacts, (2) vehicle emissions impacts.

Global warming, energy and land use impacts: Biomass ethanol has long attracted interest as a renewable fuel that could potentially reduce fossil fuel dependence, improve national energy security, and reduce climate change impacts. Provided feedstocks are sustainably managed, any carbon released by the combustion of a biomass fuel is theoretically offset by the removal of an equivalent amount of carbon from the atmosphere through the regrowth of feedstocks. In practice, the climate picture is considerably more complex when agricultural inputs, production process energy inputs, and land use changes are taken into account. In fact, until recently the net climate impacts of corn-based ethanol were thought to be minimal given the relatively input intensive nature of corn cultivation and the energy intensity of the corn-to-ethanol conversion process.

More recent analysis conducted by the Center for Transportation Research at Argonne National Laboratory suggests that corn-based ethanol has positive net climate change and energy security benefits when recent improvements in agricultural productivity and corn-to-ethanol conversion efficiency are taken into account. However, these benefits are still substantially less than the benefits that could theoretically be realized from cellulosic ethanol production. The Argonne researchers concluded that whereas each gallon of corn ethanol could achieve net greenhouse gas benefits of 12 to 26% relative to an equal quantity of gasoline; cellulosic ethanol could achieve greenhouse gas benefits of 80 to over 130% relative to gasoline.³⁵ From an energy

35 The Argonne analysis considered the use of ethanol in three gasoline blends: E10, E85, and E95 (corresponding to blends containing 10%, 85%, and 95% ethanol, respectively). The results summarized here reflect those calculated for each gallon of ethanol used in one of these blends (not on a per vehicle

security standpoint, corn ethanol was found to reduce petroleum use by more than 90% and overall fossil energy use by over 40%, compared to gasoline. Meanwhile, it was estimated that the use of cellulosic ethanol could reduce petroleum use by close to 90% and overall fossil energy use by close to 100%.

The specific full fuel-cycle global warming and energy security benefits attributable to ethanol depend on a host of assumptions embedded in the analysis. In general, wet milling appears to produce smaller greenhouse gas (GHG) reductions than dry milling in the case of corn ethanol. Similarly, herbaceous feedstocks are generally found to have lower GHG benefits compared to woody feedstocks in the case of cellulosic ethanol. The precise magnitude of GHG reductions and petroleum displacement estimated in the Argonne analysis varies depending on how co-products (in the case of corn ethanol) and excess energy production (from lignin-cogenerated electricity in the case of cellulosic ethanol) are ‘credited’.³⁶ The results also depend on assumptions concerning vehicle fuel economy improvements that could be achieved on different ethanol blends. For instance, the Argonne analysis assumes that a vehicle running on a 95% ethanol blend could achieve a 10% mile-per-gallon fuel economy improvement over a vehicle running on a 10% ethanol blend.³⁷

In terms of land-use and other environmental impacts (fertilizer run-off, ecosystem diversity, and habitat preservation), cellulosic ethanol is similarly thought to offer certain advantages relative to corn-based ethanol. This is largely because potential cellulosic feedstocks could encompass a greater variety of crop types that generally require less intensive cultivation and fewer agricultural inputs relative to corn and other grains. Nevertheless, it should be noted that general concerns have been raised about the potential ecosystem and land-use impacts associated with large-scale expansion of plantation-type dedicated biomass energy crops. Of course, to the extent that cellulosic ethanol production utilizes wastes and residues (whether municipal or food wastes, agricultural or mill residues, waste paper, etc.), land-use and other environmental impacts may be minimal or non-existent. Indeed these impacts could even be positive in cases where the diversion of biomass wastes for purposes of ethanol production relieves pressure on landfills or avoids other disposal options that have negative environmental impacts.

mile basis). On a per vehicle mile basis, the GHG benefits of using E10 are much lower (ranging from 1.5% in the case of corn ethanol up to 8% for cellulosic ethanol), because the amount of ethanol used relative to gasoline is fairly small at this blend ratio.

36 For instance, the net fuel-cycle benefits of cellulosic ethanol depend on how much electricity is assumed to be cogenerated and on the type of electricity production that is assumed to be displaced.

37 As a result, the benefits shown in the Argonne analysis for each gallon of ethanol used in E85 and E95 are generally larger than those calculated for each gallon used in E10. To the extent that ethanol is used to replace MBTE in conventional and reformulated gasoline (rather than as an alternative fuel in specially designed vehicles), however, it would likely be at ratios closer to E10.

Summary

Based on the foregoing discussion, there appears to be one oxygenate (ethanol) and one non-oxygenate (toluene) that are currently available in sufficient volume to replace MTBE in the near term. More analysis is needed of the ability to rapidly expand alkylate production. Of course, reliance on a mix of options may present the most reasonable approach to an eventual phase-out of MTBE in the Northeast. The next section discusses regulatory options that may be available toward that end.

V. Cost Estimates and Refinery Modeling

Refinery modeling by the U.S. Department of Energy (DOE) and the California Energy Commission (CEC) suggests that ethanol would be the primary replacement for MTBE if the latter were phased out of existing clean fuels programs. Regulatory options that result in replacing MTBE with ethanol are estimated to increase the cost of a gallon of gasoline by 2.5 cents. In addition to ethanol, alkylate and aromatics would likely contribute to the replacement of MTBE, depending on the regulatory approach taken. However, the DOE cost estimates assume that refineries will only meet the minimum regulatory requirements for toxic air emissions, which will in effect result in a substantial increase (40% or more) in toxic air emissions in the Northeast. In addition, the DOE estimates assume emission increases from the conventional gasoline pool, and allows refineries to produce ethanol and non-ethanol gasoline blends which will result in VOC increases due to commingling in vehicle gas tanks.

In 1998, refineries that supply gasoline to the Northeast overcomplied with Phase II RFG toxic performance standards by more than 75%, in part due to the presence of MTBE. It is this substantial margin of overcompliance that may be lost if MTBE is reduced or eliminated from RFG. In addition, toxic air emissions from conventional gasoline sold in the Northeast have declined by 13% since 1990, and those emissions benefits may also be diminished or lost if MTBE is phased out of RFG. NESCAUM is particularly concerned about increases in air toxic emissions because ambient levels of mobile source air toxics already far exceed health-based risk standards in the Northeast (see white paper on health impacts).

To date, no modeling has been performed to estimate the cost of preserving the air quality benefits of the current RFG program while phasing down or removing MTBE. NESCAUM strongly recommends additional refinery modeling to determine the costs associated with a phase down of MTBE while preserving current levels of air toxic reductions in the RFG and conventional gasoline pools. A more detailed description of the refinery and economic modeling runs NESCAUM recommends is provided in Appendix A.

VI. Status of State Actions to Reduce MTBE Use in the Northeast

While recognizing that national or regional action is preferable to individual state action with respect to the regulation of gasoline and fuel additives, several RFG states have already taken action to address concerns over growing MTBE contamination of their water resources. The following is a brief summary of the actions taken in Maine, New Hampshire, Connecticut and California.

A State of Maine

On October 13, 1998, Governor King sent a letter to USEPA indicating Maine's decision to opt out of the federal RFG program. This decision was predicated on the findings of a state Bureau of Health study that the higher levels of MTBE in RFG were statistically linked to the risk of groundwater contamination. The report concluded that the current levels and persistence of MTBE in groundwater did not constitute an immediate public health crisis, but raised concerns that continuation of the federal RFG program would result in an exacerbation of the problem. Believing that the state lacked the authority to remain in the RFG program and adequately regulate MTBE levels in fuel, the decision was made to opt out of the RFG program altogether.

The RFG program opt out was approved by USEPA as of February 1, 1999 with the following conditions: (1) Maine must identify alternative control measure(s) to provide equivalent VOC reductions to the RFG program; (2) a schedule for implementing the replacement measure(s); and (3) Maine provide an explanation of the impact to the State Implementation Plan for ozone.

As a replacement measure, Maine has adopted a low volatility conventional gasoline initiative. No gasoline delivered in the former RFG counties (York, Cumberland, Sagadahoc, Androscoggin, Kennebec, Knox and Lincoln) shall not have a Reid Vapor Pressure (RVP) of greater than 7.8 pounds per square inch (psi) for the period May 1 to September 15, 1999. For the period May 1 to September 15, 2000 and subsequent years, the RVP of fuels in these counties shall not exceed 7.2 psi.

Preliminary fuel quality data suggest that the amount of MTBE in gasoline has been reduced by more than 50% as a consequence of this initiative. However, aromatics have increased substantially, presumably to replace the octane lost from the 50% reduction in MTBE. Consistent with Maine's action to substantially reduce MTBE, public concern over MTBE contamination has dissipated considerably. Based on Maine's desire to maximize the potential air quality and public health benefits of cleaner burning gasoline, the state has indicated an interest in future participation in the federal RFG program should a national or regional solution emerge to adequately reduce MTBE use.

B. *New Hampshire*

In June 1999, the New Hampshire legislature adopted an *Act relative to the prevention of MTBE contamination of drinking water and groundwater*. Citing concerns about MTBE contamination of drinking water, the uncertain health and environmental impacts of alternative clean fuel formulations and current lack of state authority to regulated the MTBE content of RFG, the legislature instructed the Department of Environmental Services (DES) to seek a waiver to opt out of the RFG program until January 1, 2002. A waiver request was sent to EPA, New England on July 21, 1999 and specifically references the NESCAUM study on MTBE and potential alternatives as one of the actions New Hampshire has taken to address the issue. If approved, the section 211 waiver would allow the state to sell conventional gasoline through January 1, 2002.

The legislation also requires: continued monitoring of public and private drinking water supplies; a study of MTBE alternatives; and the adoption of primary and secondary drinking water standards. The Act further authorizes the Commissioner of DES to require lower MTBE concentrations in gasoline if readily available and reasonably priced substitute gasoline supplies exist and are approved for use in New Hampshire by the USEPA. Like Maine, New Hampshire has expressed a strong desire to rejoin the federal RFG program or a regional cleaner burning gasoline should a national or regional solution emerge to adequately reduce MTBE use.

C. *Connecticut*

The Connecticut legislature recently passed a law requiring the Commissioner of Environmental Protection to report back to the General Assembly by February 1, 2000 with recommendations on “whether the continued use of MTBE is appropriate.” The legislation explicitly mentions the NESCAUM’s work on MTBE, and requires an investigation into four specific areas: (1) whether MTBE use should be continued and if not, an explanation of the waiver process, (2) the impact of MTBE on the state’s water supply, (3) the status of other relevant state action, and (4) recommendations on alternative or supplemental air pollution reduction programs, such as alternative vehicle incentives, mass transit and employee commute programs.³⁸

D. *California*

Citing a significant environmental threat to groundwater and drinking water, on March 1999, Governor Gray Davis directed a phase-out of MTBE use in California to be completed no later than December 31, 2002. California asked USEPA for an immediate waiver from the Clean Air Act’s oxygen mandate and committed to maintaining the air quality emission standards of the RFG program. The governor also mandated a pump labeling program to inform consumers about gasoline containing MTBE. The Air Resources Board and Water Resources Control Board were directed to conduct an analysis of the environmental fate of ethanol in air and water. The Office of

38 Senate Bill Number 630, “An Act Concerning the Use of MTBE as a Gasoline Additive,” June 23, 1999.

Environmental Health Hazard Assessment will prepare an analysis of the health risks of ethanol in gasoline and the products of incomplete combustion.

VII. Conclusion

The RFG program has provided substantial air quality benefits to the Northeast since 1995. Ambient monitoring data collected before and after the implementation of the RFG program supports the conclusion that the presence of RFG helped reduce levels of carbon monoxide, total toxics, and benzene emissions in the Northeast. Program benefits are expected to increase for NO_x and VOCs when Phase II of the program is implemented in January 1, 2000.

The most pervasive air toxics driving public health risk in the Northeast are benzene, 1,3-butadiene, formaldehyde, and acetaldehyde. Motor vehicles are the dominant source of these four pollutants. Despite significant reductions in mobile source air toxics in the last several years, ambient levels of these four air toxics continue to far exceed health-based risk standards in the Northeast. NESCAUM is particularly concerned about any regulatory action that might result in increases in mobile source air toxic emissions.

If MTBE is phased down or banned without additional regulatory steps to secure current air toxics emissions performance of RFG, it is likely that mobile source air toxic emissions will increase. Refineries that supply the Northeast have overcomplied with Phase II RFG toxic performance standards by more than 75%, in part due to the presence of MTBE. It is this substantial margin of overcompliance that may be lost if MTBE is reduced or eliminated from RFG. In addition, toxic air emissions from conventional gasoline sold in the Northeast have declined 13% since 1990, and those emission benefits may also be diminished or lost if MTBE is phased out of RFG.

The use of oxygenates, such as MTBE and ethanol, contributes to reductions in air toxic emissions from motor vehicles through dilution and replacement of toxic gasoline constituents that are high in octane. Several sources of data strongly suggest that an increase in MTBE content results in a corresponding decrease in levels of aromatics, a major source of benzene emissions in motor vehicles.

Available refinery modeling predicts that over time ethanol is the most likely gasoline additive to replace MTBE, even if the oxygenate mandate is removed. A transition to ethanol would take several years to establish Northeast production or develop a distribution system. Several significant air quality issues need to be addressed before Northeast states pursue policies that result in increased use of ethanol. Combustion of ethanol-blend gasoline results in substantial (50 to 70%) increases of acetaldehyde emissions and ambient levels of acetaldehyde are presently far in excess of health-based risk standards in the Northeast. Refineries are likely to use ethanol at 10% by volume in conventional gasoline to take advantage of the statutory one pound RVP waiver, which would lead to a substantial increase in VOC emissions. For this reason, NESCAUM recommends elimination of this RVP waiver for ethanol. Unless all gasoline sold in the

region contains ethanol, the blending or commingling of ethanol-based with non-ethanol-gasoline blends in vehicle gas tanks will result in a significant increase in VOC emissions due to increases in fuel volatility. On the positive side, ethanol, and especially biomass ethanol, has the potential for reducing CO₂ emissions, eliminating the need for waste disposal, and retaining 120 million dollars a year in the Northeast economy.

There are two likely non-oxygenate alternatives to MTBE: aromatics and alkylate. The use of aromatics to replace MTBE is likely to substantially increase toxic emissions from motor vehicles operated on RFG and CG. In the Northeast, ambient levels of benzene, a known human carcinogen, far exceed health-based risk standards. Alkylate provides octane without apparent increases in toxic emissions, but are presently not available in sufficient volume to replace MTBE. Moreover, the health effects of alkylate are not well understood, and a rigorous evaluation of the potency, combustion by-products and environmental fate and transport of alkylate should be conducted prior to increasing its use in gasoline.

The desire to achieve substantial reductions in MTBE, coupled with potential legal constraints and concerns about the near-term viability of alternatives to MTBE, has led some states to opt out of the RFG program. To date, the states that have opted out of the RFG program have done so without economic hardship, but the gasoline sold in these states does not provide the air quality benefits of the RFG program. NESCAUM strongly recommends additional refinery modeling to estimate the costs associated with a phase down of MTBE while preserving current levels of air toxic reductions in the RFG and conventional gasoline pools.

Appendix A

Description of Future Refinery Modeling

Introduction

The Northeast States for Coordinated Air Use Management (NESCAUM) and member states are soliciting proposals to perform refinery modeling analysis for several scenarios related to the use of MTBE and oxygenates in gasoline. Of principal concern is the trade-off between the use of oxygenates, motor vehicle air toxic emissions, and the price of gasoline.

Premises

- Assessment of refineries in PADDs I and III, but contractor may comment on whether it is sufficient to analyze only PADD I refineries.
- Separate RFG and CG Pools
- Separate Regular and Premium Grades
- Contractor should specify intended use of aggregate or notional (i.e., typical) refinery modeling approach.
- Ratio-limited refinery modeling required
- Summer and winter analysis
- Where ethanol is used in the RFG or CG pools, it must be used for the entire RFG or CG pool to minimize gas tank commingling of ethanol and non-ethanol blends.
- All cases assume sufficient time for investment. Contractor should define how many years are required.
- Contractor should suggest a methodology for predicting future cost of ethanol to PADDs I and III refineries assuming a California phase out of MTBE. Note: The California Energy Commission study estimated the future price of ethanol under a national ban on MTBE, but this estimate is likely to underestimate the price of ethanol in the future.

Reference Case

The reference case should reflect actual emission reductions achieved from the RFG and conventional gasoline pools in the Northeast. For Phase I RFG the Northeast achieved a 30% reduction in mass toxic air emissions in 1997, and a 35% reduction in 1998. In addition, toxic emissions from the conventional gasoline pool in the Northeast have declined by 13% from 1990 levels. The reference case should consider the benefits from the RFG and CG pools, modified by necessary adjustments to meet Phase II RFG performance standards.

Cases

1. All parameters used in the reference case, but no oxygenates in either the RFG or the CG pools. This case represents a worse case scenario. It assumes that the oxygenate

mandate is lifted, ethers are banned, and ethanol is, for whatever reason, not available. This case will quantify the tradeoff between motor vehicle toxic emissions, gasoline price, and oxygenates.

2. All parameters used in the reference case, an MTBE cap of 3%, and 5%, by volume for the pool average, including RFG and CG, regular and premium. Refineries are free to use various amounts of MTBE in different pools or grades.

3. All parameters used in the reference case, but lift the oxygenate mandate. The US DOE performed a similar scenario but only for an immediate case without investment. This case differs because it allows for investment, and may represent PADD III as well as PADD I.

4. All parameters used in the reference case, maintain the oxygenate mandate, ban ethers, for PADDs I and III. US DOE has already completed an analysis of this scenario, but only for PADD I.

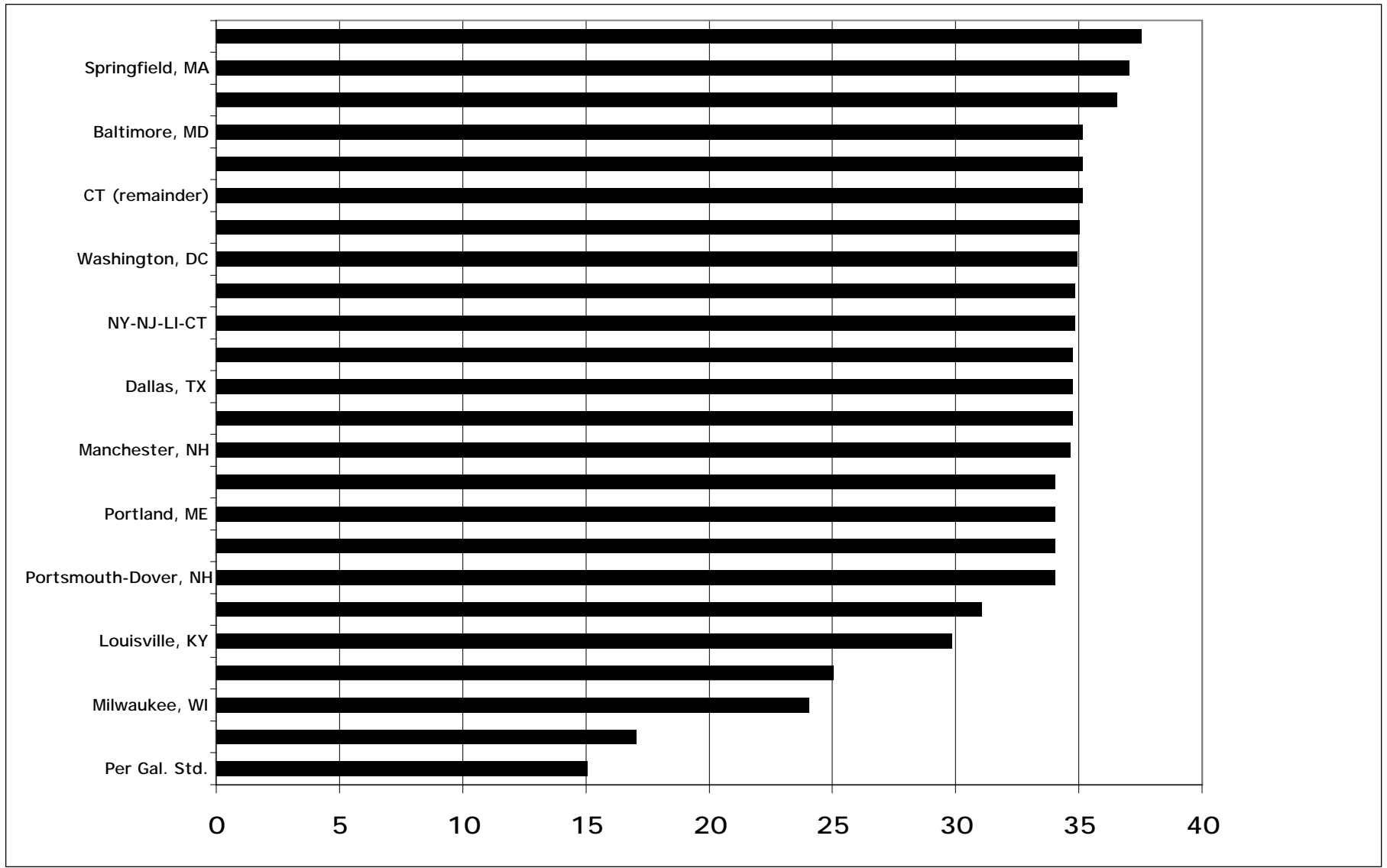
Appendix B
Preliminary Draft Fuels Data
Maine May, 1999

	TERMINAL	GRADE	RVP	MTBE	BENZENE	AROMATICS	SULFUR	OLEFINS
			psi	% wt O2	%vol	%vol	ppm	
1	Mobil	87	8.63	0.06	0.81	26.1	97	6.8
2		93	8.75	0.1	0.22	37.1	1	5.8
3		93	7.59	0.24	0.92	52	54	7.9
4		87	7.38	0.05	0.42	27.5	109	6.7
5		87	7.4	0.09	0.44	27.6	98	6.7
6		87	8.68	0.1	1.6	24.9	666	
7		87	8.54	0.03	0.28	23.3	59	5.8
8		87	7.2	0.12	0.27	29	89	4.7
9		87	8.5	0.18	1.92	34.1	637	9.6
10		93	6.57	0.09	0.86	53.7	0.005	14.2
11		93	8.73	0.04	0.39	37.9	7	4.6
12		87	7.68	0.02	0.27	30.5	82	5.7
13		87	8.68	0.09	0.56	26	73	5.8
14		87	7.52	0.05	0.32	28.3	107	5.9
Average			7.99*	0.09	0.66	32.7	148.5	6.9
Average - PADD I & Imports (1997)			8.7	2.1	0.62	19.1	229	11.6
RFG actual (1998) -- average of two samples from Portland			7.8	2.18	0.707	26.05	170	7.8

*Some of this gasoline will be sold in northern Maine or northern New Hampshire, and does not comply with Maine's 7.8 RVP standard for the southern counties.

Appendix C

RFG Survey Data, Summer 1998: Phase I Toxics Reduction



Percent Reduction from 1990 Baseline

Northeast States for Coordinated Air Use Management

Attachment IV

**The Impact of MTBE on Treatment
and Remediation of Water Resources
in the Northeast**

AUGUST 1999

TABLE OF CONTENTS

<u>INTRODUCTION</u>	3
<u>I. ESTIMATED ADDITIONAL COSTS OF MTBE REMEDIATION</u>	3
ADDITIONAL CLEANUP COSTS DUE TO THE PRESENCE OF MTBE IN GASOLINE	3
CHEMICAL PROPERTIES OF MTBE AND BENZENE	4
<u>II. HEALTH-BASED STANDARDS AND ACTION LEVELS FOR MTBE AND BTEX COMPOUNDS</u>	6
CURRENT STANDARDS	6
IMPACT OF LOWERING MTBE CLEANUP STANDARDS	8
<u>III. DIFFERENTIAL IMPACTS OF MTBE ON WATER RESOURCES</u>	9
<u>IV. TREATMENT AND REMEDIATION OF WATER RESOURCES CONTAMINATED WITH MTBE</u>	10
TREATMENT OF DRINKING WATER SUPPLIES	10
AIR STRIPPING	10
GRANULAR ACTIVATED CARBON	11
ADVANCED OXIDATION PROCESS	12
SUMMARY OF TECHNIQUES AND COSTS	12
REMEDICATION OF SOIL, SURFACE WATER AND GROUNDWATER	13
SOIL VAPOR EXTRACTION	13
AIR SPARGING	14
PUMP AND TREAT	14
NATURAL ATTENUATION OR BIOREMEDIATION	14
<u>V SUMMARY AND RECOMMENDATIONS FOR ADDITIONAL INVESTIGATION</u>	15

Introduction

This analysis of the costs and approaches to remediate methyl tertiary-butyl ether is part of a larger effort to assess MTBE's impact on public health and the environment in the Northeast. Due to its particular chemical properties and low taste and odor threshold, MTBE drives a portion of cleanup costs in the Northeast. The precise percentage depends on a number of factors, including whether the area uses federal reformulated gasoline (RFG), or conventional gasoline. In light of the significant threat that MTBE poses to potable water resources in the Northeast, environmental regulators are questioning whether to diminish use of this gasoline additive.

This paper is divided into two sections. The first section addresses seeks to determine the costs attributable to MTBE as part of regional expenditures on the cleanup of gasoline releases into the environment. Information from the NESCAUM states on remediation costs, and from a national survey conducted by the University of Massachusetts and US Environmental Protection Agency are relied upon heavily in this section. The second section describes in detail the methods used to treat drinking water and remediate surface and groundwater contaminated by MTBE. A recent document published by California water agencies, in collaboration with the oil and oxygenated fuel interests, is the primary source of information for this section since it is one of the few publications directly on point. Northeast state remediation staff provided tremendous input and insight throughout this study process.

I. Estimated Additional Costs of MTBE Remediation

Northeast states do not collect specific information on the cleanup costs of particular gasoline constituents such as benzene, toluene, or MTBE. The cost figures provided in this section are based on expert judgments of state staff in the leaking underground storage tanks (UST) programs. Information was collected from the Northeast states through a survey developed by NESCAUM and the New Hampshire Department of Environmental Services. Results from a nationwide survey conducted by the University of Massachusetts and US EPA in 1998 were used as well.

Additional Cleanup Costs Due to the Presence of MTBE in Gasoline

In 1997, the Northeast states and responsible private parties spent about \$168 million dollars to remediate gasoline spills, primarily from underground storage tanks. A precise apportionment of the costs of MTBE contamination is not available because states do not compile data on specific gasoline constituents. In order to obtain a general understanding of MTBE's relative contribution to cleanup costs of gasoline spills in the Northeast,

NESCAUM and the NH DES developed a survey on how MTBE has affected the remediation procedures, techniques and costs at state UST and drinking water programs.

Unlike the University of California Davis study, which used a groundwater dispersion model to estimate past costs and predict future costs, NESCAUM sought only to understand the incremental increase due to MTBE in cleanup costs of gasoline spills *that have already been remediated*. These actual costs provide a solid foundation for projecting MTBE's relative contribution to gasoline cleanup costs into the future. While upgrades of underground storage tanks are expected to reduce the amount of gasoline released into the environment, MTBE's relative contribution to on the cost of cleanup of gasoline spills are likely to remain constant.

In addition to the NESCAUM analysis, the University of Massachusetts and EPA conducted a national survey that found marked differences in clean up costs of gasoline spills in states with RFG and states without RFG. In RFG areas, 70 percent of the sites experienced some increase due to the presence of MTBE, and significant cost increases of more than 20 percent were found at 40 percent of the sites.¹ In contrast, the survey found that non-RFG areas experienced no cost increase from MTBE at 70 percent of the sites, and only 8 percent of the sites experienced significant cost increases due to the presence of MTBE in conventional gasoline.

Taken together, these surveys lead us to conclude that in areas in the Northeast where RFG is sold, the use of MTBE is responsible for 30 percent of the gasoline spill remediation costs, or \$40.79 million. In conventional gasoline, areas the cleanup costs associated with MTBE are only 6 percent of the total cleanup costs for the area, or about \$3.43 million. The non-RFG areas are Vermont, and portions of Maine, New York, and New Hampshire.

Chemical Properties of MTBE and Benzene

Once released into the environment, MTBE behaves differently than other gasoline compounds such as benzene, toluene, ethylbenzene, and xylene, commonly referred to as BTEX compounds. Benzene, a known human carcinogen, is the contaminant of concern

¹ Study reports LUST programs are feeling effects of MTBE releases, Soil and Groundwater Clean up, August/September 1998, Robert Hitzig, Paul Kostecki, and Denise Leonard. The Study found significant differences in the costs of gasoline clean up due to MTBE in RFG and non-RFG sites. At 70 percent of the non-RFG sites, MTBE did not increase the cost of cleanup, and very significant cost increases (greater than 50%) were found in less than 2 percent of the sites.

In contrast, 70 percent of the RFG sites experienced costs increases due to MTBE, and very significant costs increases (50% to 100%) were incurred at 10 percent of the sites, and costs doubled at 7.5 percent of the RFG sites.

at most gasoline sites because its groundwater remediation levels are usually the lowest of the BTEX compounds. However, at many sites, MTBE has replaced benzene as the chief contaminant of concern because of its presence in groundwater without the BTEX compounds, its low taste and odor threshold, its persistence in the groundwater and its lack of retardation.² Comparing the chemical characteristics of MTBE with benzene provides a theoretical understanding of MTBE's influence on cleanup costs.

- MTBE is about 30 times more soluble than benzene in water. Pure MTBE can reach an equilibrium concentration in water of approximately 5 percent (i.e., 48,000 mg/L).
- The vapor pressure of MTBE is about three times greater than the vapor pressure of benzene. Consequently, most benzene emissions from motor vehicles are found in the exhaust, while a substantial portion of MTBE from motor vehicles is released as evaporative emissions.
- When moving from the dissolved phase (e.g., groundwater) to the vapor phase, MTBE is about ten times less volatile than benzene. As a result, air stripping MTBE from groundwater, a common remediation technique, requires a higher air to water ratio, a higher stripping tower, and more time.
- MTBE is much less likely than benzene to adsorb to soil or organic carbon. The presence of MTBE in groundwater significantly increases the cost of using granular activated carbon to remediate the site.
- MTBE is resistant to biodegradation while benzene and the other BTEX compounds bioremediate relatively readily. Bioremediation methods for soil treatment – land-farming, bioventing, biopiles – are currently not recommended for removing MTBE. MTBE in groundwater is also resistant to biodegradation, and it is not considered a realistic treatment option. However, research is ongoing, and there have been some limited successes under laboratory conditions.

In general, when MTBE is in the soil, it separates from the rest of the petroleum due to MTBE's lack of adsorption to soil particles. Once in the groundwater, MTBE travels at about the same rate as the groundwater while the BTEX compounds move slowly through groundwater and biodegrade over time. MTBE forms a "halo" around the core BTEX compounds, and sometimes it forms separate plumes. This results in more costly site investigations, the need for more monitoring wells, and more samples to characterize the larger plume. Larger MTBE plumes have the potential to impact a greater number of wells, and alternative water supply for impacted individuals often leads to very high additional costs. The state of Rhode Island, for instance, generally finds that once MTBE

² EPA-822-f-97-009, Drinking Water Advisory: Consumer Acceptability Advise and Health Effects Analysis on Methyl Tertiary-Butyl Ether (MTBE), December, 1997.

has affected groundwater wells, it is more cost effective to provide residents with alternative drinking water than to treat the groundwater down to acceptable MTBE concentrations.

In addition, many gasoline spills in the Northeast are allowed to bioremediate as long as they do not threaten water supplies. MTBE's recalcitrance to biodegradation – as well as its lack of adsorption to soil particles and high solubility -- often forces state agencies and private responsible parties to actively remediate gasoline spills when MTBE is present. California's MTBE groundwater dispersion model assumed that the majority of non-MTBE gasoline spills would naturally attenuate, while if MTBE were present in the gasoline, active remediation was usually required. The situation is less extreme in the Northeast, where natural attenuation rates for gasoline with MTBE range from less than 20 percent to 40 to 60 percent.

II. Health-based Standards and Action Levels for MTBE and BTEX Compounds

Current Standards

All eight Northeast states have established standards and/or action levels for the clean up of groundwater, drinking water, and soil contaminated with MTBE. Nationwide, about 23 states have adopted remediation standards for MTBE. Action levels trigger cleanup requirements. Once triggered, cleanup must result in contaminant levels at or below the standard. Some states set their soil cleanup levels in order to protect groundwater underneath the soil.

Health-based cleanup standards for MTBE in groundwater and drinking water are usually identical, and range between 20 ppb in Rhode Island to a high of 100 ppb in Connecticut (see Table 1).³ Soil remediation standards for MTBE are roughly an order of magnitude higher than standards for groundwater and drinking water. Most soil standards are set at 2 ppm, but some soil action levels are set much lower in order to protect groundwater.

³ Connecticut is considering lowering its groundwater and drinking water standard for MTBE to 70 ppb.

Table 1
MTBE Action Levels and Standards in the Northeast

State	Groundwater (ppb)	Drinking Water (ppb)	Soil
New York	50 ppb action level	50 ppb standard and action level	1000 ppb action level
New Hampshire	70 ppb standard and action level	70 ppb standard and 15 action level	2 ppm standard and action level
Connecticut	100 ppb standard	100 ppb action level	-- 2 ppm GA pollution mobility criteria -- 500 ppm residential direct exposure criteria
Maine	35 ppb standard and 25 action level	35 ppb standard and 25 action level	5 ppm for total gasoline including MTBE for stringent sites ⁴
Vermont	Site specific based on receptors.	40 ppb standard and 1.0 action level	Site specific based on receptors
New Jersey	70 ppb standard	70 ppb standard	70 ppb standard
Massachusetts	70 ppb action level and standard	70 ppb action level and standard	0.3 ppm
Rhode Island	20 ppb standard	20 ppb standard	No soil standard

At sites contaminated with gasoline, benzene and MTBE are the two primary drivers of cleanup costs due to their relatively low health-based standards and action levels. Groundwater and drinking water standards for MTBE range from 20 ppb to 100 ppb, while standards for benzene range from 1 to 5 ppb in the Northeast states. The rest of the BTEX compounds are less hazardous and their standards typically range from about 500 ppb to 10,000 ppb in Connecticut and Massachusetts.⁵ However, New York State's maximum contaminant level for toluene, ethylbenzene and each isomer of xylene is 5 ppb. In most cases, if a site is remediated sufficiently to achieve its benzene remediation standard, the other BTEX compounds are well below their remediation standards as well.

Prior to the use of MTBE in significant quantities, benzene was the determining factor in the cost of gasoline spill cleanup. It is present in gasoline at low levels, ranging in volume from 0.6 percent in RFG to about 1.4 percent in conventional gasoline in the Northeast. Its octane rating of 101 is significantly lower than those of other aromatics such as toluene (103 octane), xylene (106 octane), and even non-aromatic MTBE (110 octane). Refineries sell benzene as a chemical feedstock, which is reflected in the price of a gallon of benzene at 69 cents per gallon while the rest of the octane-enhancers cost around 50 cents a gallon. Ambient benzene levels exceed health-based risk standards in many areas

⁴ Non-stringent sites where groundwater is not threatened have a higher standard 500 – 1,000 mg/kg.

⁵ Connecticut groundwater cleanup standards (ug/L) for various gasoline constituents from lowest to highest: benzene 1 ppb, MTBE 100 ppb, xylenes 530, ethylbenzene 700, toluene 1000. Massachusetts: 5 benzene, ethylbenzene 700 ppb, toluene 1000, xylene 10,000.

of the Northeast, according to 1990 modeled data by the EPA cumulative exposure project and Northeast states ambient monitored data. When performing a holistic examination of the costs and benefits of various gasoline constituents in terms of air quality and water quality, the elimination of benzene as a component of gasoline must be seriously considered.

Impact of Lowering MTBE Cleanup Standards

Recent legislation in New Hampshire and proposed regulations in California suggest a trend to lower MTBE groundwater remediation standards to below 20 ppb due to greater public concerns about health risks and taste and odor sensitivities. Lowering the MTBE remediation standard from 50 ppb to 10 ppb could double cleanup costs. In New York State, costs at a gasoline spill were projected to increase from roughly \$300,000 to about \$600,000 if the stringency of groundwater remediation standards for MTBE were increased from 50 ppb to 10 ppb (a greater volume of the plume has to be treated to achieve the lower limit). Table 2 below presents the projected costs at a New York gasoline spill site in East Patchogue.

Table 2
Groundwater Water Remediation Levels and Cost Estimates
in the Northeast

Groundwater Remediation Level (ppb)	Cost Estimate
1,000	\$150,000
50	\$300,000 to \$350,000
10	\$620,000 to \$710,000

An estimate by a New York State contractor read as follows: “At 75 gallons per minute (gpm), there is still no major difference between 1 ppb benzene and the 50 ppb MTBE effluent. Reducing MTBE to 10 ppb causes an increase in the air to water ratio from 85 to 221 (850 cfm to 2120 cfm). Although this would translate into minimal differences in initial cost, and again depending on other design variables, this could cause a 250% increase in operating (electric) costs.”

In addition, as reported in the NESCAUM survey by NY DEC, remedial systems must be oversized to treat effectively for MTBE. The capital costs for equipment are higher but the real increased costs come from operational expenses (i.e., utilities, maintenance, monitoring) which must be maintained for long periods. In addition, options for treating

MTBE plumes are typically limited to extraction and treatment processes, which in many cases cost more than alternative methods available for treating just BTEX plumes.

III. Differential Impacts of MTBE on Water Resources

The volume percent of MTBE in gasoline generally increases the amount of groundwater contamination in the area. For example, RFG and Oxy-Fuel is sold in the 10 counties around New York City, and most of the highest MTBE contamination is found in this area. In addition, a New York State Department of Health interim study shows that private wells located near gas stations that supply RFG are three times as likely to have groundwater contaminated with significant (>20%) levels of MTBE. Similar results were found in the Maine study on groundwater contamination by MTBE.

However, even at relatively low levels, once MTBE reaches groundwater, it plays a significant role in the cost of cleanup. Point of entry (POE) systems are required when groundwater has been contaminated and passive cleanup is not possible. In RFG and non-RFG Northeast states, about half the POE systems are required *solely* because of the presence of MTBE at the site (e.g., CT at 50% of POE sites, NJ at 40%-60% of POE sites, ME has 255 filters on wells contaminated with MTBE, Vermont 50%). In New York State, many point of entry remediation systems are installed to remove only MTBE. These percentages are due to MTBE's large plumes and low remediation thresholds required to satisfy taste and odor concerns.

The reason MTBE is the sole contaminant in about half the POE treated groundwater aquifers in the Northeast is that over time, the MTBE plume, or plumes, separate from BTEX compounds.⁶ This divergence of plumes leads to new costs due to the presence of MTBE in gasoline. These figures also suggest that MTBE may pose a cumulative contamination hazard due to its apparent recalcitrance and mobility.

Underground storage tank staff have been addressing groundwater contamination problems due to MBTE many years prior to the advent of oxy-fuel in 1992 and RFG in 1995. For example, Connecticut has been treating for MTBE at an action level of 100 ppb for approximately 12 years (Reported on the UMASS / EPA survey in 1998 by Peter Zack, Connecticut Department of Environmental Protection).

⁶ In a study conducted at 29 sites in San Diego County from 1992 to 1996, the probability of co-occurrence of MTBE and BTEX compounds detected in individual monitoring wells decreased significantly over time from 80 percent to 60 percent over three years.

IV. Treatment and Remediation of Water Resources Contaminated with MTBE

This section reviews the techniques and costs of removing MTBE from water resources. There are three primary treatment technologies for removal of MTBE from drinking water: air stripping, advanced oxidation process, and granular activated carbon. Remediation options for surface and groundwater impacted by MTBE include soil vapor extraction (SVE), air sparging, pump and treat, and bioremediation. The remediation options discussed for surface water are based on methods originally designed for treatment of drinking water. The costs associated with each technique depend upon level of concentration, removal efficiency, and the applicable drinking water standard or water remediation standard.

Treatment of Drinking Water Supplies

Proven technologies for treatment of drinking water supplies include air stripping, advanced oxidation, and activated carbon. MTBE concentrations in drinking water can range up to 2,000 ppb, compared to treated water quality goals or standards which range from non-detect to about 70 ppb. Treatment systems must achieve removal efficiencies of 90 percent or above in many cases.

Air Stripping

Air stripping has been successfully used to remove MTBE from drinking water (e.g., Rockaway Township, NJ). The two common air stripping configurations are packed towers and shallow trays. Packed towers are more effective, but shallow trays are more compact. In packed towers, a tall, cylindrical tower is filled with plastic elements and the water is pumped to the top and allowed to trickle over the elements, exposing a thin layer of water to the air being blown in the bottom (see Appendix A for diagram of air stripping by packed tower). Shallow trays force large amounts of small air bubbles through water to form a froth, and the volatiles escape into the air as it passes through the water.

The MTBE Research Partnership, which includes the Association of California Water Agencies, the Western States Petroleum Association, and the oxygenated Fuels Association, has determined that packed towers are the most cost-effective air stripping technology for removal of MTBE from drinking water. Total amortized costs per 1,000 gallons for packed towers typically range from 30 to 40 cents for low flow (60 gpm) and 8 to 10 cents for high flow (6000 gpm). Treatment of evaporated MTBE may be required when daily emissions exceed one pound. Exceedance of the one-pound threshold often occurs when MTBE concentrations exceed 200 ppb under moderate flow (600 gpm).

There are two primary technologies for treatment of MTBE evaporative emissions, or off-gases. Carbon adsorption is more cost effective at low off-gas MTBE concentrations with costs of about 16 cents per 1,000 gallons of water treated. Thermal oxidation is the preferred choice when off-gas MTBE concentrations exceed 5 ppm (vapor). Costs per 1,000 gallons of water treated range from a high of 82 at low flow conditions to 25 cents under high flow conditions. MTBE is less readily removed, or stripped, from water than other gasoline constituents, such as toluene and benzene.

Air stripping is the least expensive method currently available to treat drinking water supplies contaminated with MTBE. Annual treatment costs for a family of four range from about \$50 for air stripping, to about \$120 for ozone/hydrogen peroxide, to about \$160 for granular activated carbon (MTBE Research Partnership). Treatment costs vary significantly depending on the volume of water treated. For example, MTBE treatment cost of air stripping with off-gas treatment ranges from about 50 cents per 1,000 gallons per minute to about 25 cents for 6 million gallons minute.

Granular Activated Carbon

Granular activated carbon, commonly referred to as GAC, has seen increasing use in commercial applications as water quality regulations become more stringent and is now widely used for the removal of synthetic organic compounds (SOCs). These filters can remove chlorine, chlorinate by-products, and volatile organic compounds such as MTBE, and some non-organics. Activated carbon can be added to regular sand filters to enable these devices to remove organics from the water such as MTBE. MTBE molecules do not adhere to GAC as readily as other VOCs such as benzene (see Appendix A for diagram of granular activated carbon).

Filters using activated carbon are popular in consumer water filters primarily to address taste and odor problems with tap water. Prices for residential activated carbon filters range from less than \$100 for a single, low volume tap to over \$1,000 for a whole house unit. Although not a preferred solution, it is possible to treat private well water containing low levels of MTBE with a residential granular activated carbon filter system.

Activated carbon removes particles by the process of adsorption. Adsorption is the assimilation of gas, vapor, or dissolved matter by the surface of a solid or liquid. Activated carbon has an extremely large surface area (500 to 1,400 square meters per gram). Everything, including the water, is adsorbed, but the binding of the water is weak and reversible. Large organic molecules like most VOCs are held very strongly, as are most compounds that impart color, taste and odor to the water. Activated carbon that is used up can be recharged or “regenerated” by heating it to temperatures of 820 to 930

decreases C. In addition, substantial VOCs can be liberated from GAC (i.e., carbon regeneration) through steam injection at temperatures far less than 820-930 degrees C.⁷

Advanced Oxidation Process

Advanced oxidation processes remove contaminants by passing ozone, ultraviolet light, or hydrogen peroxide, through the water. AOP's have been used successfully for drinking water applications, primarily for disinfection and sometimes for VOC removal. AOP is used in Europe to disinfect drinking water supplies, but very few studies are available on the topic of AOP for VOC removal. The MTBE Research Partnership estimated costs per 1,000 gallons of drinking water treated by hydrogen peroxide and ultraviolet light to range from about 90 cents to \$1.40 for low flow rate and 20 cents to 75 cents for high flow rates. The Research Partnership recommends pilot projects for these techniques prior to full scale commercial application (see Appendix A for diagram of Advanced Oxidation).

Summary of Techniques and Costs

According to the MTBE Research Partnership, the total amortized costs per 1,000 gallons of water treated for each of the water treatment technologies described in this section are presented below in Table 3.

Table 3
Total Amortized Costs MTBE Treatment Technologies
(per 1,000 gallons)

Flow Rate	Influent Concentration (ppb)	Effluent Concentration (ppb)	Packed Tower	Packed Tower with Off-gas	Granular Activated Carbon	Advanced Oxidation H ₂ O ₂ /Uv
60	200	5	.37	.53	1.17	1.50
600	200	5	.14	.31	.52	.97
6000	200	5	.09	.26	.28	.91
600	20	5	.07	.24	.13	.41

Air stripping with a packed tower is the most cost effective technology for treatment of drinking water resources contaminated with MTBE at 200 ppb concentrations. Granular activated carbon is the best choice for water contaminated at relatively low levels of

⁷ New York State Department of Environmental Conservation, personal communication, August, 1999.

MTBE at 20 ppb. GAC is the second choice at higher MTBE concentrations, and has the added benefit of wide use in commercial drinking water applications. The least cost-effective method is advanced oxidation process, which would probably also require a pilot project prior to full-scale implementation of this option.

Remediation of Soil, Surface Water and Groundwater

There are many mature methods and technologies available for cleaning up gasoline that has been released into the environment. They differ from treatment technologies for drinking water resources when remediation takes place in the environment without removing the contaminated media. This broad category of remediation is commonly called *in situ*. Once removed, the water containing MTBE or other VOCs is treated with many of the same technologies and method used to treat drinking water. This section focuses on the in-situ category of remediation methods and technologies.

Proven technologies for clean up of soil contaminated with MTBE include soil vapor extraction (SVE), soil heating/ SVE, and excavation. Groundwater cleanup is typically performed with pump and treat, air sparging, or multiple phase vacuum extraction.

Costs range depending on the size of the release, the remediation standard, and the proximity of sensitive environmental areas, such as drinking water aquifers. For soil cleanup, costs range from low to high from no action, to soil vapor extraction, to tank removal, the excavation and on-site treatment, to excavation and off-site disposal, to steam injection and recovery. For impacted groundwater, cleanup costs start at no action, monitored natural attenuation, free product recovery, enhanced biodegradation, air sparging, multi-fluid vacuum extraction, and pump and treat.

MTBE's affect on remediation costs are site specific. Costs range from no impact to significant increase depending on plume size. Greater numbers of sites may require active remediation. Emerging technologies show potential for cost reduction (i.e., enhanced biodegradation). Underground storage tank upgrades combined with proper enforcement should reduce the number and magnitude of releases. Early detection and expeditious response to releases should lower costs considerably.

Soil Vapor Extraction

There are usually no additional costs associated with MTBE during soil remediation of gasoline spills. MTBE contaminated soils can be effectively remediated by soil vapor extraction, a process of moving air through the soil to release the contaminants. MTBE does not adsorb strongly to soil particles, and vaporizes readily once contacted with air.

These technologies must be used soon after the spill occurs to prevent MTBE from contaminating the groundwater.

Air Sparging

Air sparging removes MTBE from groundwater by pumping air through the groundwater to strip MTBE from the groundwater into the airstream, and by the possible stimulation of aerobic bio-degradation of MTBE in the groundwater. However, air sparging may inhibit naturally occurring reductive biodegradation of MTBE in groundwater (EPA/625/K-98/001, USEPA Seminars: Monitored Natural Attenuation for Groundwater, September 1998).

Pump and Treat

The most common cleanup method is pumping the groundwater out of the aquifer and treating it above ground, better known as pump and treat. This method is effective at lowering concentrations of MTBE, but requires higher pumping rates and higher air to water ratios than are required for BTEX removal alone.

Once above ground, water containing elevated levels of MTBE is typically treated with technologies described in the previous section on drinking water treatment. MTBE increases the cost of activated carbon filters because it requires more frequent changing of the carbon. At low concentrations of under 300 ppb of MTBE in groundwater, New York and New Jersey regulators have found granular activated carbon effective. New York regulators experience shows that a 2 cubic foot carbon bed will last a month in a typical single family home application with MTBE at concentrations of 100 ppb. Air stripping systems are capable of removing MTBE in a relatively cost effective manner, but very high air to water ratios are necessary.

Natural Attenuation or Bioremediation

Natural attenuation is usually not an option due to MTBE's resistance to biodegradation, but it is an inexpensive way to remediate gasoline spills without MTBE. While a number of laboratory-cultured microorganisms can degrade MTBE, there is no convincing evidence to date that this destructive process occurs quickly or commonly in the field. While future research is warranted, it is appropriate to manage groundwater resources with the assumption that MTBE is both mobile and recalcitrant relative to benzene, until proven otherwise (see Appendix A for diagram of biological treatment).

V. Summary and Recommendations for Additional Investigation

This section finds that the presence of MTBE in gasoline sold in the Northeast has materially increased the cost of cleaning up gasoline spills.

- MTBE chemical properties cause it to behave differently than other gasoline constituents such as benzene in the environment. MTBE is more soluble than benzene, does not adhere to soil particles, and is not readily biodegraded. Consequently, MTBE is a significant contributor to cleanup costs.
- The presence of MTBE in gasoline, even at low levels, increases the cleanup costs of gasoline spills. The percent increase in cleanup costs due to MTBE rises with the amount of MTBE in the gasoline. In RFG areas in the Northeast, MTBE is responsible for about 30 percent of gasoline spill cleanup costs, or about \$41 million annually. In areas where conventional gasoline is sold, cleanup costs due to MTBE are only about 6 percent of the total remediation cost of gasoline spills, or about \$3.4 million.
- In general, MTBE does not pose unique remediation problems when it is in the soil, but once in the groundwater, it increases the scope, difficulty, and cost of the cleanup efforts. For instance, the presence of MTBE at a groundwater contamination site increases the cost of delineating the site, requiring more monitoring wells. At times, MTBE creates two plumes instead of one BTEX plume. Because of its resistance to biodegradation, passive remediation techniques are usually not employed. Other remediation methods such as granular activated carbon and air stripping are more expensive when MTBE is involved.
- Groundwater cleanup standards for MTBE and benzene drive the cost of the cleanup. MTBE groundwater cleanup standards range from 20 ppb to 100 ppb in the Northeast states. Benzene's remediation standards are set between 1 and 5 ppb, while the rest of the BTEX compounds are much higher (e.g., toluene 1000 ppb). Some contractors and state experts estimate that lowering MTBE cleanup standards from 50 ppb to 10 ppb will double remediation costs.
- When performing a holistic examination of the costs and benefits of various gasoline constituents in terms of air quality *and* water quality, the elimination of benzene as a component of gasoline must be seriously considered. Benzene is responsible for a large percentage of gasoline spill cleanup costs and ambient levels of benzene. At 1 percent or less by volume for most gasoline sold in the Northeast, its octane benefit to refineries is marginal and its value as a chemical feedstock is reflected in its price of 40 percent over traditional aromatic octane supplements.

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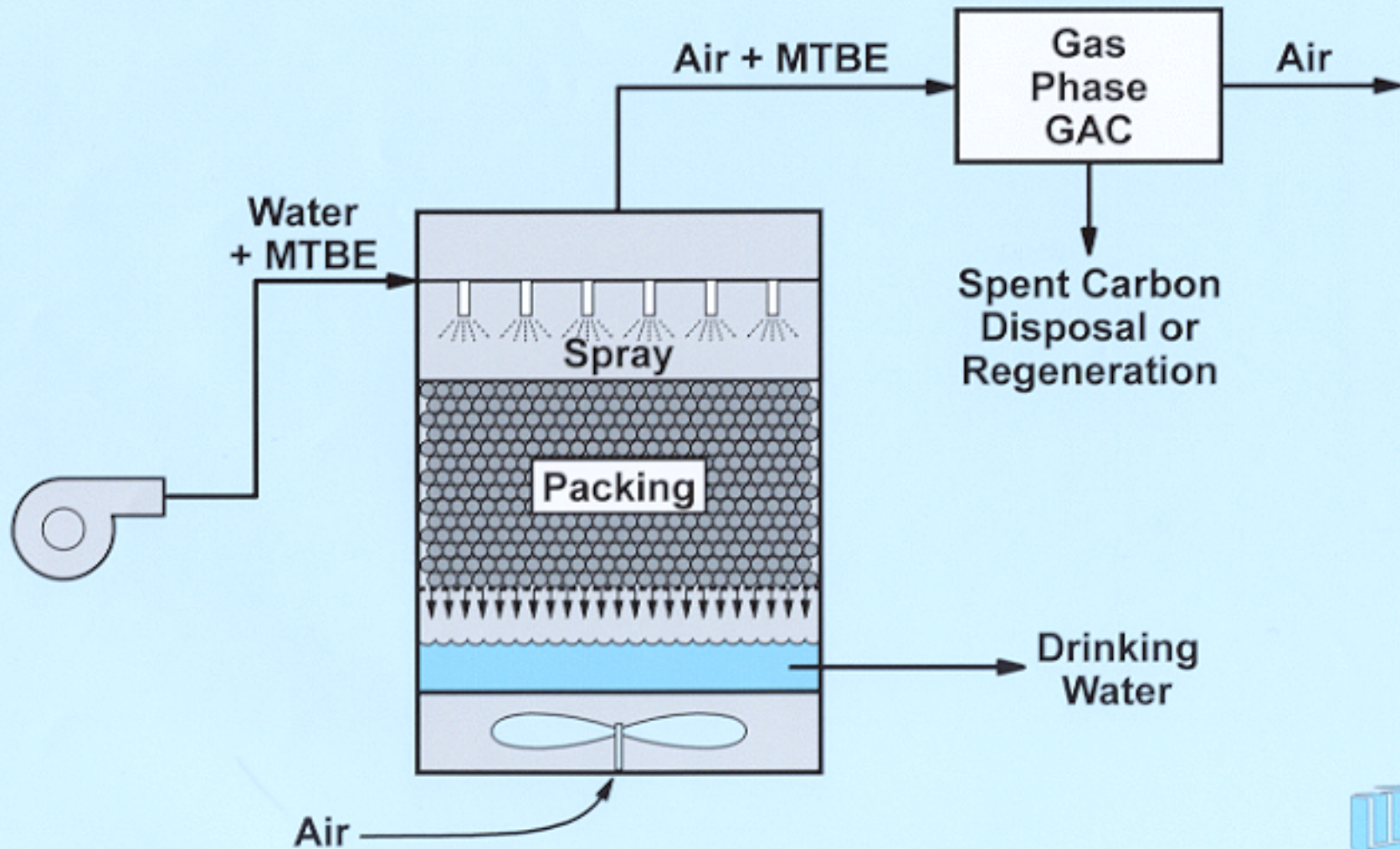
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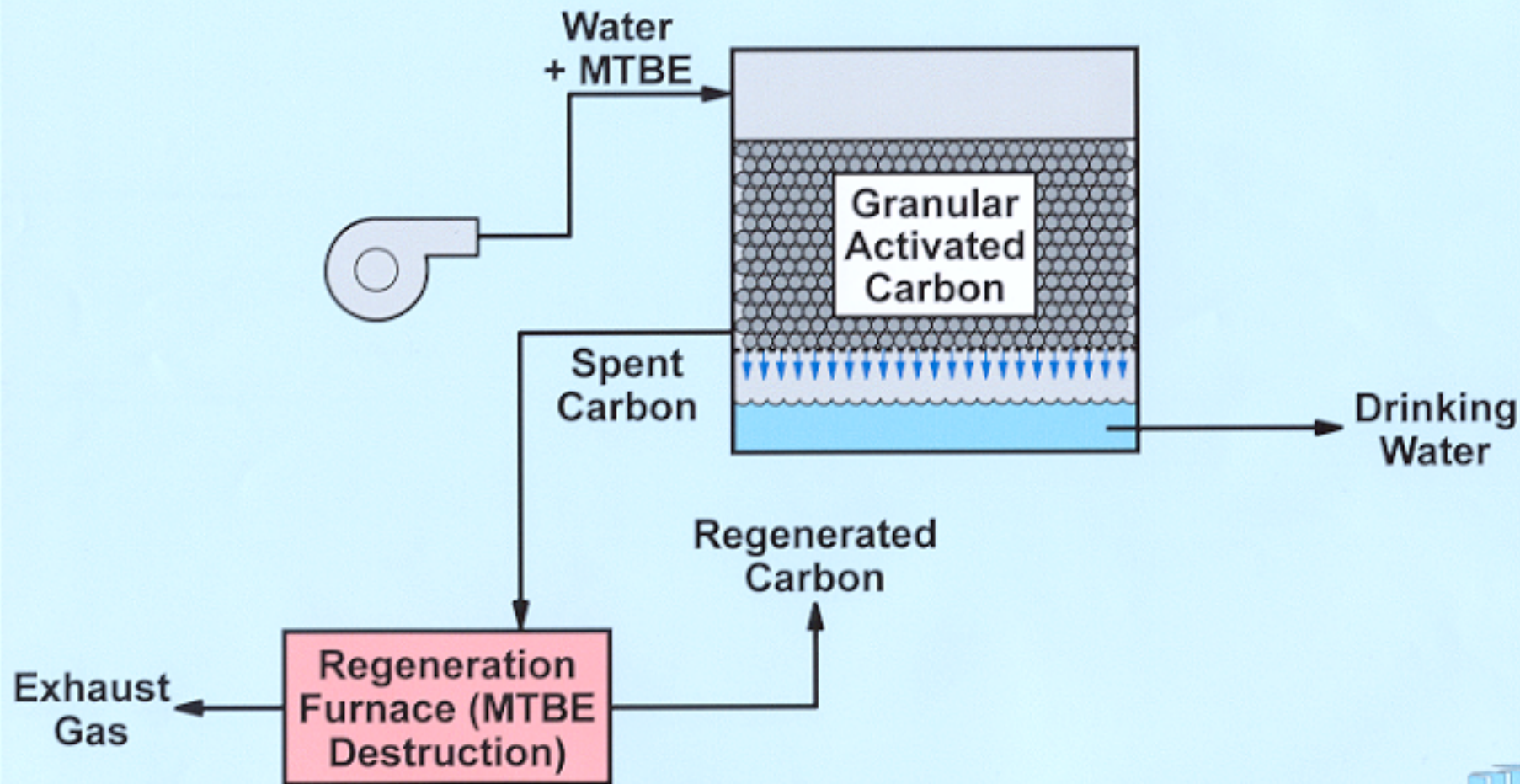
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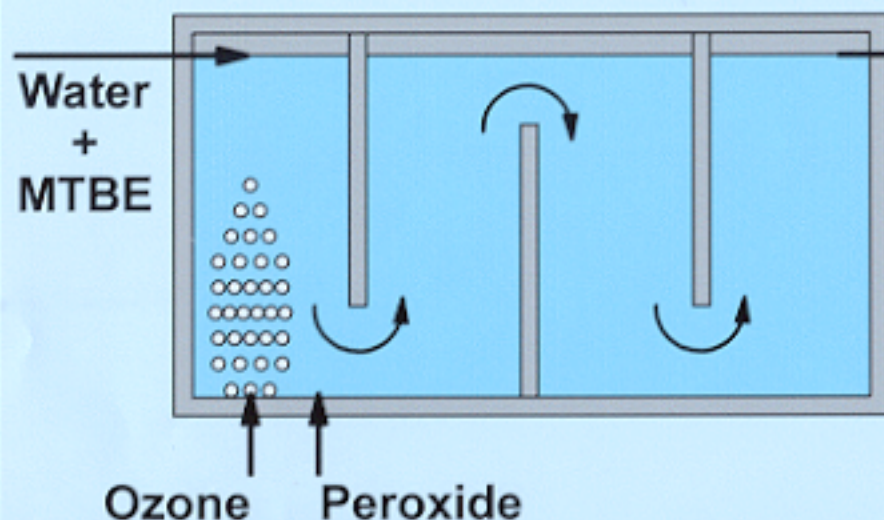
Air Stripping: Packed Tower



Granular Activated Carbon



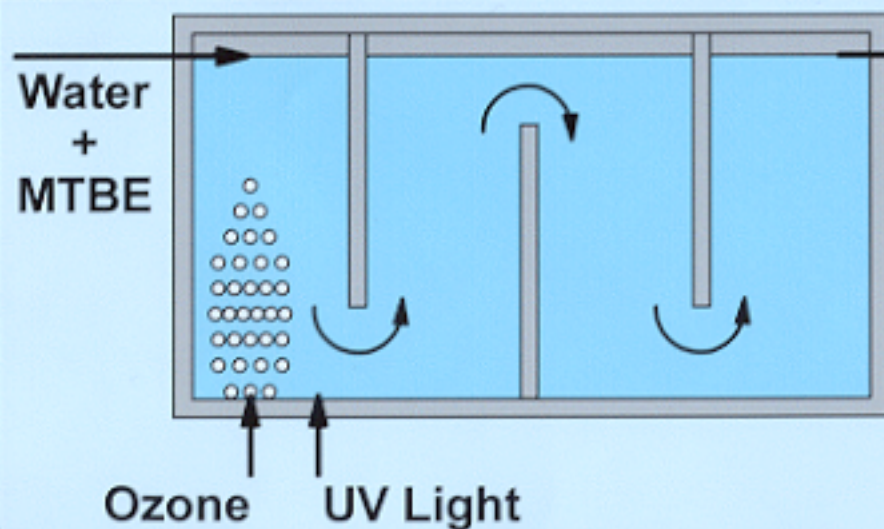
Advanced Oxidation (Hydroxyl Radical)



Drinking Water
Ozone/Peroxide

Byproducts:

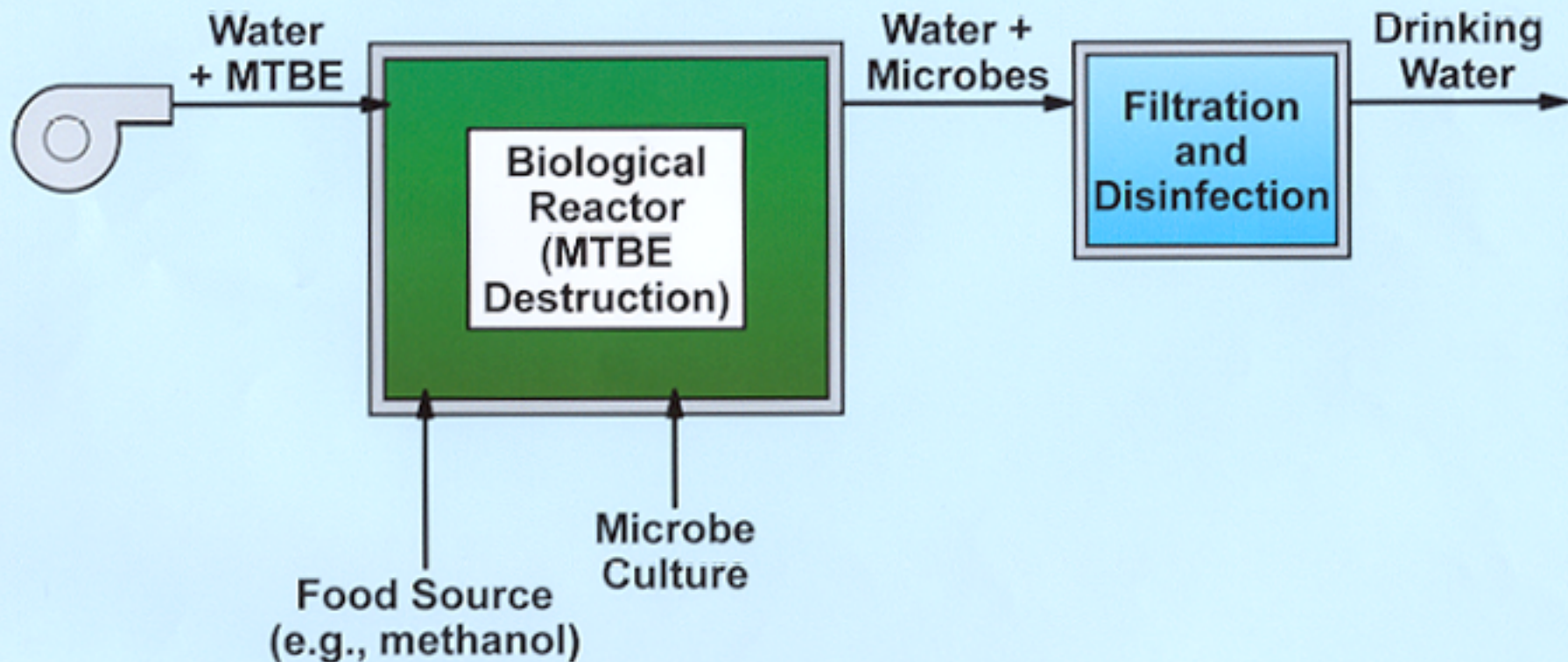
- Bromate
- Aldehydes
- Assimilable Organic Carbon
- t-Butyl Alcohol
- t-Butyl Formate
- Acetone



Drinking Water
Ozone/UV



Biological Treatment



Byproducts: Unknown

