# HEALTH, ENVIRONMENTAL, AND ECONOMIC IMPACTS OF ADDING ETHANOL TO GASOLINE IN THE NORTHEAST STATES



**NESCAUM**
Northeast States for
Coordinated Air Use
Management

## VOLUME 2

### *AIR QUALITY, HEALTH, AND ECONOMIC IMPACTS*

**JULY 2001**

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### JULY 2001

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# ACKNOWLEDGEMENTS

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# CHAPTER I

# OVERVIEW

*T*he federal reformulated gasoline (RFG) program provides important public health benefits in the Northeast states by reducing exhaust and evaporative emissions of smog precursors and toxic or "hazardous" air pollutant (HAP) emissions from motor vehicles. Within the eight-state NESCAUM region, only the New York City and Hartford, Connecticut metropolitan areas are required to sell RFG. However, a substantial number of other areas have voluntarily opted into the program through January 1, 2004; consequently, as much as three-quarters of the gasoline sold in the Northeast market is RFG. Participation in the federal RFG program has been an important component of state strategies for reducing violations of the federal ozone standard in the region and will be needed in continuing efforts to control smog. Motor vehicles and fuels are also the primary source of public health risks associated with exposure to toxic air pollutants. Participation in the RFG program is a proven strategy for reducing emissions of these pollutants.

The federal Clean Air Act (CAA) requires that RFG contain a minimum of 2 percent oxygen by weight. Methyl *tertiary*-butyl ether (M*t*BE) has been the primary oxygenate used by refiners supplying gasoline to the Northeast to meet this requirement because it is relatively inexpensive, has clean-burning characteristics and provides a good source of octane. However, M*t*BE poses a threat to water resources because of its high mobility in groundwater and its resistance to biodegradation. Since the introduction of RFG in 1995, M*t*BE has been detected in an increasing number of private and public water supplies. Due to taste and odor characteristics that affect the drinkability of M*t*BE-contaminated water even at low M*t*BE concentrations, as well as concern about possible acute and chronic health effects, a broad consensus has emerged that the use of M*t*BE in gasoline should be curtailed.

State and federal policymakers and affected industries are looking for ways to maintain the air quality benefits of the RFG program while reducing or eliminating the threat that M*t*BE poses to water resources.[1] Unless Congress eliminates the CAA's current oxygenate requirement for RFG [2] or the U.S. Environmental Protection Agency (USEPA) grants waivers to individual states, RFG must continue to contain 2 percent by weight oxygen. Since several states in the Northeast have banned M*t*BE and most others support a reduction in M*t*BE use, an alternative oxygenate must be used in RFG. At present, it appears that the only viable oxygenate alternative to M*t*BE is ethanol; other alternatives (such as E*t*BE) either have the same undesirable physical and chemical properties as M*t*BE or cannot be produced on the scale necessary to satisfy near-term demand. Ethanol has been used as a gasoline additive in parts of the country, especially the Midwest, for some time. While its use in the Northeast has been minimal to date, some companies already sell ethanol-blended gasoline in New England.

To better understand the implications of reducing M*t*BE use, Northeast state Environmental Commissioners have asked the New England Interstate Water Pollution Control Commission (NEIWPCC) and the Northeast States for Coordinated Air Use Management (NESCAUM) to evaluate the health, environmental and economic impacts associated with a large-scale increase in the region's use of ethanol. It should be

emphasized that this report is intended to respond to that request, not to provide the rationale for past policy decisions taken by the Northeast states. As such, this analysis takes as a given that (1) M*t*BE will be phased out or substantially reduced in the region's future gasoline supplies and (2) ethanol will play an increased role as a substitute for M*t*BE. It should be noted that NESCAUM has not performed any new research but has rather confined its analysis to a presentation of existing information. In this context, the technical white paper focuses on air quality-related health impacts and economic impacts associated with changes in fuel formulation and infrastructure needs. It also covers the potential for developing biomass ethanol production capacity (based on feedstocks other than corn) in the Northeast. The companion NEIWPCC report (Volume 3) covers water quality impacts and related public health and environmental issues associated with increased ethanol use. Findings from both documents were used to generate a shorter summary report with recommendations for the northeastern states (Volume 1).

Together with the summary report, this technical white paper is the most recent installment in a series of studies by NESCAUM regarding the RFG program and various fuel constituents. If the policy landscape changes as a result of Congressional or state actions that would significantly alter gasoline reformulations and potentially diminish the role of ethanol in favor of other fuel constituents, further work will be needed to properly inform the region's policymakers on the potential consequences of such actions.

This white paper is organized into three broad sections comprising Chapters II, III, and IV respectively. The first, Chapter II, discusses the impact of curtailing or banning the use of M*t*BE in terms of fuel formulations, demand for different fuel constituents, and fuel and emissions characteristics. Chapter III then addresses the air-quality related health risks associated with increased exposure to ethanol, as well as the health impacts associated with toxic and criteria pollutant emissions from ethanol-blended gasoline. Chapter IV turns to the potential economic and regulatory impacts of a large-scale shift to ethanol to meet the oxygenate requirements of the RFG program in the Northeast, including the need for new or modified transport, storage and distribution infrastructure. Because the development of indigenous ethanol production capacity, using biomass feedstocks other than corn, could substantially affect the economics, as well as the environmental impacts of ethanol use in the Northeast, this topic is covered separately in Chapter V.

## OVERVIEW ENDNOTES

[1] Note that, in the near term, opting out of the federal RFG program is not an option for most areas that have voluntarily opted into the program. To give refiners investment certainty with regard to future demand for RFG, states that did not opt out of the RFG program by the end of 1997 are required by USEPA to stay with the program until at least January 1, 2004. Among NESCAUM states, only Maine opted out by the end of 1997.

[2] Legislative proposals to remove or modify the current oxygenate mandate were debated in the last Congress, but have so far been unsuccessful.

# CHAPTER II

# REFORMULATING RFG WITHOUT M*t*BE

## A. INTRODUCTION

*T*he following section summarizes available technical information on the effects of substituting the gasoline oxygenate, ethanol, for M*t*BE, with respect to vehicle performance and emissions. Although fuel oxygenates have been an important strategy in reducing automobile carbon monoxide and toxic emissions, the widespread replacement of M*t*BE with ethanol could result in increased ozone precursor and toxic emissions from vehicles operating on either RFG or conventional gasoline. This may include increases in:

▲ tailpipe emissions (specifically NOx);

▲ evaporative VOC and toxic emissions; and

▲ indirect transportation emissions of NOx, particulate and toxics.

Changes in emissions are expected due to the combustion characteristics of ethanol, the interaction of ethanol with other constituents of gasoline and necessary changes to the gasoline blendstocks. The overall composition of gasoline will likely change due to the volume difference between M*t*BE and ethanol needed to meet the RFG oxygen requirement, differences in octane characteristics of the two oxygenates and differences in the chemical interactions of ethanol with other constituents of gasoline. Specifically, the overall volatility of gasoline can increase substantially upon the introduction of ethanol.

The inferences made in this analysis regarding emission impacts due to ethanol substitution for M*t*BE are hampered by gaps in the available scientific literature. Many emission test results predate the commercial availability of RFG and, therefore, do not reflect the differences in the composition of gasoline blends currently in use, particularly with respect to RVP performance standards. Furthermore, past studies have typically focused primarily on M*t*BE blends.

The final section of this chapter deals with indirect emission impacts of substituting ethanol for M*t*BE. These impacts are emissions associated with the transport of fuel ethanol from the current areas of production (the Midwest) to the Northeast. Although these impacts are not expected to be substantial, they may result in increased exposure to particulates and other toxic emissions at certain locales including storage depots and blending facilities.[1]

## B. GASOLINE BASICS

Gasoline is a complex mixture of hundreds of chemical compounds. It is primarily composed of hydrocarbons, which are molecules made up of different combinations of hydrogen and carbon. In simple terms, the internal combustion engine is a system of pistons and cylinders that transforms the chemical energy of gasoline into mechanical energy by oxidizing (combusting) hydrocarbons. The four-stroke internal combustion engine powers nearly all gasoline-fueled automobiles. Typically, a controlled mixture of atomized fuel and air is delivered to a cylinder; the mixture in the cylinder is compressed by a piston and then ignited by means of a spark plug. The resulting combustion drives the piston down, transmitting power to the crankshaft and thence to the wheels.[2] This process results in exhaust gases, which include oxidized carbon and hydrogen (in the form of water and carbon dioxide), as well as other combustion by-products, such as oxides of nitrogen (NOx), carbon monoxide (CO), volatile organic compounds (VOCs) and particulate matter (PM). NOx are formed from the chemical reaction of ambient nitrogen and oxygen

at the high temperatures present in the combustion chamber, while CO, VOC and PM are formed from unburned hydrocarbons resulting from incomplete combustion. Notably, VOC emissions result not only from the combustion of gasoline, but also from the evaporation of fuel in the gas tank, permeation through fuel lines and hoses and during refueling at the gas station. In automobiles, exhaust PM is generally associated with older, poorly maintained cars, which consume lubricating oil, although VOC and NOx contribute to secondary PM formation in the atmosphere.

Since the mandated de-leading of gasoline in the early 1970's, the regulation of motor fuels has been used in combination with vehicle emissions standards to reduce air pollutant emissions associated with motor vehicle use. In 1992, the federal government began to require that oxygen-containing chemical compounds (oxygenates) be added to some gasoline to reduce the CO emissions that result from incomplete fuel combustion, particularly under cold weather conditions. These "oxyfuel" requirements apply to areas in violation of National Ambient Air Quality Standards (NAAQS) for CO and, as CO is a wintertime problem, require that gasoline sold in the wintertime contain 2.7 percent oxygen by weight.[3] Currently, the only CO nonattainment area in the NESCAUM region is the New York City Consolidated Metropolitan Statistical Area (CMSA) (excluding the Connecticut portion, which has been re-designated as in attainment of the CO NAAQS).[4] Improvements in engine and vehicle design have minimized the need for fuel based CO reductions allowing some states, such as New York and New Jersey, to substitute year-round use of federal RFG (with its somewhat lower oxygenate requirement) in place of the oxyfuel program.

The federal RFG program was introduced as part of the Clean Air Act Amendments of 1990 for the primary purpose of reducing emissions of ozone precursors (mainly NOx and VOCs) and toxic emissions from automobiles. As previously noted in Chapter I, the program requires that RFG contain 2 percent oxygen by weight. For a variety of reasons including cost, availability, ease of transport (especially in pipelines) and performance properties, M*t*BE has emerged as the primary oxygenate used in most parts of the country to meet this requirement to date. To meet the 2 percent by weight requirement, M*t*BE is generally present in RFG at 11 percent by volume.

In addition to complying with the oxygenate mandate and other specific requirements of the RFG program, gasoline must be formulated to meet a number of specifications established by the American Society for Testing and Materials (ASTM) to ensure uniform fuel performance in a variety of vehicles and under widely different operating conditions.[5] A particularly important parameter of gasoline performance is octane, which is commonly displayed on black and yellow decals posted at the gasoline pump and represents a measure of the fuel's ability to resist knocking.[6] Engine knock occurs when the fuel-air mixture in the combustion cylinder ignites prematurely in the high-compression environment typical of modern automobiles, and is often accompanied by a characteristic pinging sound.[7] Knocking results in a loss of power and can lead to engine damage. Higher octane gasoline is more resistant to knock, as measured by ASTM's Antiknock Index rating (AKI).

Another important fuel parameter is volatility or the fuel's ability to move from the liquid phase to the vapor phase. One characterization of fuel volatility especially pertinent to air quality regulators is Reid Vapor Pressure (RVP), measured in units of pounds per square inch (psi). Because highly volatile gasolines will evaporate more readily, leading to excessive evaporative hydrocarbon emissions, both RFG and conventional gasoline are formulated to meet certain RVP limits. If RVP is too low, on the other hand, vehicle start-up and running performance may be adversely affected, especially under cold-weather conditions. Table II-1 shows the influence of volatility on vehicle performance.

The formulation of gasoline to meet performance requirements and environmental standards is complex. Individual chemical components of gasoline all have different octane and volatility characteristics; moreover, the properties of these constituents sometimes change in the presence of other fuel components. Similarly, some hydrocarbons are significantly more resistant to knock (i.e., higher in octane) than are others.[8] As it turns out, some amount of M*t*BE and/or ethanol

**Table II-1**   Effects of gasoline volatility on vehicle performance.[9,10]

| VOLATILITY TOO LOW | VOLATILITY TOO HIGH |
| --- | --- |
| Poor cold start (RVP effects) | High evaporative emissions/ canister overload & purge (RVP effects) |
| Poor warm up performance (RVP does not effect) | Hot driveability problems/ vapor lock (RVP effects) |
| Poor cool weather driveability (RVP does not effect) | Fuel economy may deteriorate (RVP does not effect) |
| Increased deposits (RVP does not effect) -crankcase -combustion chamber -spark plugs | |
| Unequal fuel distribution in carbureted vehicles (RVP does not effect) | |

would likely be used in gasoline even without an oxygenate mandate because both compounds function as octane-enhancers. As such, they can—and have—displaced more toxic octane-enhancing gasoline constituents such as benzene. In fact, M*t*BE was initially developed as an octane enhancer and blended into domestic gasoline as early as 1979 as a substitute for lead.

The air quality goals of the reformulated gasoline program have been largely successful, providing an effective strategy for reducing pollutant emissions that contribute to smog, CO, fine particulate matter, haze, acid deposition, and toxic air pollution.[11] As a complement to vehicle emissions standards, the environmental regulation of fuels has played a critical role in advancing air quality objectives. Importantly, the benefits of cleaner fuels accrue immediately upon introduction of the fuel. These benefits apply to all gasoline-powered engines, regardless of their age and design (though of course the magnitude of benefits will vary from engine to engine). By comparison, the full benefits of new vehicle emissions standards are subject to a substantial time lag as new vehicles only gradually replace older ones (90 percent turnover of the on-road fleet occurs in 12 to 15 years).

## C. FUEL REQUIREMENTS UNDER THE CURRENT RFG PROGRAM

The requirements of the federal RFG program are stipulated under §211 of the Clean Air Act. The primary purpose of the program, as noted previously, is to reduce motor vehicle emissions of ozone forming VOCs and NOx during the summer months, as well as year-round emissions of certain toxic air pollutants.[12,13] The Act stipulates that RFG must be sold in the nine most polluted ozone non-attainment areas, which include the greater New York City metropolitan area, greater Connecticut[14] and the Philadelphia metropolitan area, which encompasses Trenton and parts of New Jersey.[15] Other areas of the Northeast have chosen to participate in the federal RFG program on a voluntary opt-in basis.[16] Though their participation is voluntary, these areas are (with the exception of Maine[17]) constrained from opting out of the program until January 1, 2004 (see previous discussion in the Overview to this report). Figure II-1 shows all areas of the U.S. that currently require RFG.

The federal RFG program is now in its second phase. The first phase, in effect from 1995 to 1999, established certain requirements for the content and properties of gasoline including the 2 percent oxygenate requirement, restrictions on toxic air emissions (including benzene and other aromatics), and summertime RVP limits. The second phase of the federal RFG program took effect

on January 1, 2000. In its Phase II RFG performance standards for VOC, the Act requires a reduction of no less than 25% from baseline emissions.[18]

**Figure II-1** Federal reformulated gasoline areas.[19]



The use of performance standards, rather than detailed fuel specifications in the federal RFG program, was intended to give refiners compliance flexibility and thereby reduce compliance costs. Performance standards also provide the flexibility to choose more cost-effective overall compliance strategies which may result in individual fuels that exceed one or more of the performance standards. As indicated in Table II-2, the emissions reductions required under the RFG program are significant, especially for VOCs and toxics. The compliance of any given RFG blend with the RFG performance standards is determined by entering values for selected fuel properties of that particular fuel into the Complex Model. The Complex Model then provides an estimate of the reduction in emissions for a 1990 baseline gasoline blend which is compared against the relevant VOC, NOx and toxics performance standards for compliance.[20]

In practice, refiners have achieved even greater than anticipated reductions from federal RFG during Phase I of the program. Table II-2 summarizes reductions in VOC, NOx and toxics emissions achieved by Phase I RFG in the Northeast (as predicted by the Complex Model) compared to Phase I and II emissions performance standards. Overcompliance has been especially dramatic with respect to toxics, where emission reductions of 35 percent have been achieved (on a mass basis), though the applicable Phase I performance standard required only a 16.5 percent reduction. This overcompliance can be attributed to the mandated use of an oxygenate (primarily M*t*BE), which effectively displaced more toxic octane enhancers (such as benzene and other aromatic components), and to changes in the demand for other gasoline constituents in the manufacturing and petrochemical markets. During Phase I, for example, high demand for benzene in the petrochemical industry drove up the cost of this blendstock. Therefore, refiners had an incentive—beyond the emission limits and oxygenate requirements of the CAA—to replace benzene with M*t*BE, a less expensive octane enhancer. As a result, Phase I RFG tended to over-comply with both the benzene cap and the toxic emission standards applicable at that time.

**Table II-2**   Emissions reductions from Federal RFG in the Northeast states.[21]

| POLLUTANTS | PHASE I RFG (1995 – 1999) | | PHASE II RFG (2000+) |
|---|---|---|---|
| | *Performance Standards (% reduction from 1990 gasoline specifications)* | *Actual Emission Reductions in Northeast Market* [22] | *Performance Standards (% reduction from 1990 gasoline specifications)* |
| VOCs | 17.1% | 21% | 27.4% |
| NOx | 1.5% | 5% | 6.8% |
| Toxics (mass emissions) | 16.5% | 35% | 21.5% |

Though M*t*BE had been in use prior to the introduction of federal RFG, its use expanded considerably with the start of the program in 1995. M*t*BE is now present in about 70 percent of all gasoline (conventional and reformulated) sold in the U.S. Figure II-2 shows the relative size of RFG vs. conventional gasoline markets in each of the eight NESCAUM states in 1999 (note that M*t*BE is present in some of the conventional gasoline sold in the region, as well as in RFG). Overall, RFG accounts for approximately three-quarters of the region's total gasoline market. Gasoline demand has, of course, continued to grow in recent years. By 1999, sales of RFG had reached roughly 11.8 billion gallons out of a regional total of 15.3 billion gallons. At 11 percent by volume, this suggests that M*t*BE use in the region is now over 1 billion gallons (nearly 31 million

**Figure II-2**    1999 Reformulated (RFG) and conventional (CG) gasoline retail sales in the Northeast.[23]
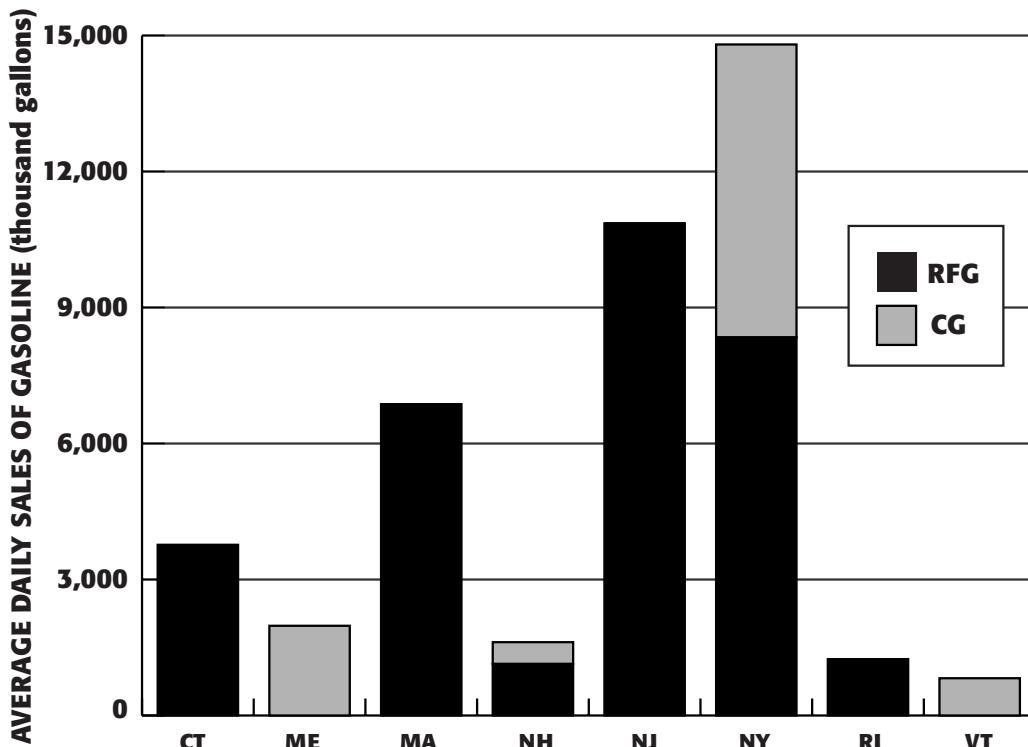
barrels) annually. If M*t*BE use is phased out, replacing this substantial volume with other fuel constituents is likely to result in significant changes to the composition of RFG and potentially to conventional gasoline as well. This may also result in a substantial volume shortfall in the region's fuel supply. This short fall could be exacerbated by other changes in fuel formulations needed to make ethanol blends compliant with current RFG requirements (for further discussion please see Section IV). Changes to both types of fuels will need to be considered in a comprehensive assessment of the impacts of an M*t*BE phase-out. In addition, it will be important to compare changes in emissions characteristics, especially in the case of toxics, relative to the actual performance achieved in Phase I of the current program using M*t*BE. Because of the overcompliance noted in Table II-2, future changes to the composition of RFG through the removal of M*t*BE could result in an *increase* in actual toxic emissions even as refiners comply with Phase II requirements.

## D. ALTERNATIVES TO M*t*BE

If states ban M*t*BE and current federal RFG requirements remain unchanged, an alternative oxygenate must be used to comply with the 2 percent oxygen mandate. Oxygenates fall into two chemical categories: ethers and alcohols. M*t*BE has been the leading ether-based oxygenate; others include ethyl *tertiary* butyl ether (E*t*BE) and *tert*-amyl methyl ether (TAME). The primary alcohol oxygenates are ethanol, methanol and *tertiary*-butyl alcohol (TBA).

The extent to which any of these oxygenates might be used in place of M*t*BE would depend on availability, performance characteristics and cost relative to other alternatives. The long-term use of other ether-based oxygenates, such as E*t*BE and TAME, for example, may be limited by the same water quality concerns that have prompted calls for a phase-out of M*t*BE. As a class, ethers are soluble in water and resistant to biodegradation; consequently, ether contamination of soils and surface/ground water environments is difficult to remediate.[24] Although there is little scientific information or field data on the behavior of E*t*BE or TAME when leaked or spilled, these compounds are expected to behave much like M*t*BE due to their similar chemical composition. Of the alcohol alternatives, use of methanol is likely to be limited by its relative toxicity and other undesirable characteristics when blended directly with gasoline.[25] Meanwhile, supplies and the production capacity of TBA (an M*t*BE metabolite) are limited.[26] Furthermore, there is evidence that TBA may be carcinogenic. Nevertheless, some potential for increased use of other ethers, methanol or TBA cannot be ruled out in the event that M*t*BE is banned while the oxygenate requirement remains in place. For these reasons, an oxygenate waiver should be granted for RFG so as not to force gasoline blenders into using a product that may have negative public health and/or environmental repercussions.

More than any of the other oxygenate alternatives, ethanol (also called ethyl or grain alcohol) is widely considered to be the primary replacement option for M*t*BE.[27] It is the only viable non-ether oxygenate that could be produced in quantities capable of supplanting a substantial portion of the M*t*BE market in the near term (i.e., over the next three to five years). Moreover, ethanol is considered relatively low in toxicity compared to many other gasoline constituents (such as benzene), it biodegrades readily, does not sorb to sediments or soils, and it does not present taste and odor issues when present at low concentrations in water, such as those associated with low concentrations of M*t*BE. The last issue of taste and odor may not be an advantage, as either taste or odor could be used as a type of early detection to sensitive populations.[28] However, like M*t*BE (which has an octane rating of 110), ethanol (with an octane rating ranging from 115-118) also functions as an octane enhancer and can therefore displace other, more toxic octane enhancers.

Despite these similarities, replacing M*t*BE with ethanol will not be straightforward and is likely to result in other changes to the formulation of both RFG and conventional gasoline.[29] First, even small amounts of ethanol raise the volatility (RVP) of gasoline. To limit evaporative hydrocarbon emissions, the allowable RVP of both conventional gasoline and RFG are effectively constrained

(see Figure II-3). To meet summertime VOC performance standards, refiners will need to use specially formulated, low-RVP base gasoline when blending RFG with ethanol. Second, ethanol has higher oxygen content than M*t*BE. As a result, RFG need only contain 5.7 percent ethanol (by volume) to meet the minimum 2 percent (by weight) oxygenate requirement. By comparison, M*t*BE is present at 11 percent by volume in most current RFG formulations. This discrepancy in volume between M*t*BE and ethanol will be discussed in greater detail further in this analysis. Suffice it to say that the competing issues of oxygen concentration, sensitivity of RVP and the octane boosting potential of ethanol must all be accounted for when determining the final blend of RFG.

Whether refiners will add ethanol to RFG at more than the 5.7 percent volume minimum required under the existing oxygen mandate if M*t*BE use is curtailed will depend on the relative cost, emissions characteristics, and octane properties of competing fuel constituents. Future market dynamics are difficult to predict and are likely to be strongly influenced by the demand for ethanol and other constituents in fuel markets besides the Northeast (notably, in California and the Midwest). On the one hand, refiners will have an incentive to add ethanol at 10 percent by volume to take full advantage of available tax credits.[30] On the other hand, they may prefer to shift any excess ethanol to the conventional gasoline pool where 10 percent ethanol blends (E10 blends) may be eligible for RVP waivers in addition to the tax credit.[31,32] To the extent that only the minimum volume of ethanol required to meet oxygenate requirements is used in RFG, other fuel constituents will be needed to make up the resulting 5 percent volume gap and an octane shortfall of approximately 1.5 octane points.[33] Alkylates are among the few high-octane, low toxicity alternatives available, but supplies are limited and alkylates are relatively costly.[34] Refinery modeling conducted by USDOE predicts that refiners will limit ethanol content in RFG to 5.7 percent, and will then shift high-octane, low-toxic constituents (such as alkylates) to RFG in favor of producing E10 blends for conventional gasoline markets.

Several Northeast states and California have banned M*t*BE. California has sought a federal waiver from the current RFG oxygen requirement but has been rejected by EPA. With the denial of their waiver request, and short of a Congressional act to lift the current oxygenate mandate, California is essentially reliant on ethanol as its oxygenate alternative. In the unlikely event that this mandate is lifted, refiners will have a greater range of options in formulating RFG without M*t*BE. Importantly, California has argued that this greater flexibility would allow refiners to blend gasolines that achieve superior environmental performance compared to the ethanol blends that will effectively be mandated under a continued oxygen requirement.

If the oxygen requirement were waived or lifted, it is highly likely that some amount of ethanol would still be blended into RFG and possibly CG due to its superior octane characteristics and relatively low toxicity, although it would have to be cost competitive with other octane enhancing compounds, such as alkylates (which also have relatively low toxicity) or aromatics (which have relatively high toxicity). On March 29, 2001, EPA published its final rule on the control of Hazardous Air Pollutants From Mobile Sources, 40 CFR Parts 80 and 86 (66 FR 17230). This rulemaking, based on CAA §202(l), caps toxic components of RFG and CG at their 1998-2000 levels. Unfortunately this rule sets the level of individual refiner and importer compliance on a national average level, thus there is no protection against increased toxics emissions within a given state or region (due to backsliding against historically low levels of toxic pollutants; see Table II-2 and relevant discussion).

In the event of a waiver or lifting of the oxygen requirement, refiners would also be free to make greater use of alkylates and—to the extent feasible within the recent CAA §202(l) rulemaking—aromatics such as benzene, toluene and xylene (all of which have octane ratings ranging from 101 to 106). Toluene is likely to be the more viable aromatic substitute for M*t*BE; it is cost-competitive, less toxic than benzene, and has high octane. Furthermore, toluene is already the most common hydrocarbon purchased for use as an octane enhancer and production capacity may already exist to allow it to substitute for much of the volume lost from removing M*t*BE. Iso-octane (2,2,4 trimethylpentane), an alkylate, has an octane rating of 100 and would be similarly attractive to refiners as an octane booster. A particular advantage of this compound is that it can be produced

from converted M*t*BE production facilities, thereby providing a solution for refinery assets that might otherwise be stranded when M*t*BE is phased out.

## E. EMISSIONS IMPACTS OF REPLACING M*t*BE WITH ETHANOL

Federal (and, in some cases, state) requirements with respect to criteria pollutant emissions, toxic air emissions, and volatility limits must be met by both conventional and reformulated gasoline, regardless of *whether ethanol replaces MtBE or not*. At the same time, new vehicles will have to continue to meet applicable tailpipe and evaporative emissions standards. Nevertheless, the large-scale substitution of M*t*BE by ethanol has the potential to alter vehicle emissions characteristics—particularly for older vehicles in the early years of an M*t*BE phase-out—in both reformulated and conventional gasoline markets. Three categories of emissions changes are discussed in the sections below: changes in tailpipe emissions; changes in evaporative hydrocarbon emissions; and indirect emissions associated with the transport of ethanol to the Northeast via barge, tanker truck, or rail. Of these, the potential for change in evaporative hydrocarbon emissions—especially in cars not equipped with sophisticated new vapor recovery systems—is likely to be the most significant and difficult to quantify.

The dearth of available information related to the effects of ethanol on RFG and subsequent vehicle emissions is a concern to NESCAUM. A majority of studies on the subject of ethanol usage as an oxygenate predate the use of RFG, therefore ethanol blending was performed on either conventional gasoline, which was the only gasoline available at the time, or a blend of gasoline that approximated the composition of RFG. A bulk of the available studies stemmed from the Auto/Oil Air Quality Improvement Research Program (AQIRP).[35] Although the AQIRP attempted to test a broad variety of gasoline blends with a range of oxygenates, the primary focus was on M*t*BE, as it was supposed that this was the most promising oxygenate. Thus, within the universe of studies examining the effects of oxygenates on vehicle emissions, few specifically examine ethanol as a gasoline oxygenate.[36] As a result, NESCAUM is forced to extrapolate this data to describe the potential emission effects that ethanol-blended oxygenated RFG will have on motor vehicle emissions.

Of further note, the discussion of emissions impacts in this section generally assumes that ethanol will be blended into RFG at 5.7 percent by volume—the minimum needed to comply with the current 2 percent by weight oxygen requirement. As indicated earlier in this chapter, there will be some incentive to blend ethanol at 10 percent, depending on cost and supplies; hence available information on the emissions impacts of E10 blends are noted, as appropriate.

### E.1  Changes in Tailpipe Emissions

Tailpipe emissions tests on cars using ethanol and other gasoline blends reveal that the addition of ethanol reduces exhaust emissions of carbon monoxide (CO), as well as total and non-methane hydrocarbons and benzene *relative to non-oxygenated blends*. However, there is no significant difference between ethanol and other oxygenates (including M*t*BE) as a means of producing these emissions reductions. As stated in Section B in this chapter, oxygenated fuels can achieve significant exhaust CO reductions. This is especially true in older and less well maintained vehicles, in which oxygenates can also achieve significant exhaust hydrocarbon reductions.[37,38] Newer technology engines are designed to minimize the amount of incomplete combustion and hence the amount of CO produced. As newer technology vehicles displace older vehicles, the need for fuel based CO reductions will decrease. EPA's projections suggest that by 2004, when the fleet is comprised almost entirely of vehicles with electronic fuel controls, oxygenates will provide little in the way of CO benefits. Notwithstanding, CO nonattainment and maintenance areas in the NESCAUM region may retain a need for wintertime CO mitigation, which includes the use of oxygenates in gasoline.

The effect of oxygenates on NOx emissions is less certain; theoretically, adding oxygenate could lead to higher NOx emissions relative to non-oxygenated blends, especially at higher oxygenate

concentrations. Recent empirical data suggest that ethanol does not have an effect on NOx exhaust emissions, relative to M*t*BE-blended gasoline, when blended at 5.7 volume percent. However, there is strong evidence that ethanol, when blended at 10 volume percent, appears to cause an increase in tailpipe NOx emissions.[39,40,41,42] Importantly, this effect is not predicted by the Complex Model, which shows a slight decrease in NOx emissions for all oxygenated blends, including those using ethanol. The Complex Model—which was developed as a regulatory compliance tool rather than as an emissions model—does not account for the NOx impacts of oxygenated fuels and in general, may not accurately characterize the range of emissions changes that could result from the substitution of ethanol or other additives for M*t*BE in reformulated gasoline.[43] As a result, the fact that ethanol blends would have to meet the same performance standards as current M*t*BE blends may not ensure that there is no change in actual on-road emissions so long as compliance is based on the current Complex Model. The potential for NOx emissions impacts that would not be captured by the Complex Model is of particular concern to the extent that tax incentives or other factors cause refiners to blend ethanol at more than the 2.0 percent weight minimum (e.g., at 10 percent by volume).

In addition to unforeseen changes in NOx emissions due to shortcomings of the Complex Model, there are at least two other categories of potential emissions impacts associated with the use of ethanol in RFG.

1. Changes in the *composition* of exhaust hydrocarbon emissions, including (most notably) an increase in acetaldehyde and ethanol emissions and a decrease in formaldehyde and M*t*BE emissions (which are predicted by the Complex Model); and

2. The potential for a loss of toxic emissions benefits relative to historic *overcompliance* with the RFG program's toxic emissions limits and benzene cap (overall changes in toxic emissions could include changes in both evaporative and tailpipe emissions)

Changes in hydrocarbon exhaust emissions, especially aromatic and other air toxic emissions, due to a M*t*BE-ethanol oxygenate switch, are difficult to quantify from individual study results, with the exception of emissions of four pollutants: M*t*BE, ethanol, acetaldehyde and formaldehyde. Furthermore, the method for blending oxygenated fuels for a majority of the research performed was to splash blend the oxygenate into an industry baseline, conventional gasoline.[44,45,46,47] Thus, no adjustments were made to the RVP, the aromatic content, or the other more volatile components of gasoline, such as the butanes, as would be seen when blending ethanol to RFG.

Formaldehyde is a transformation by-product of incompletely combusted M*t*BE. Thus, intuitively, removal of M*t*BE from gasoline will reduce both M*t*BE and moderately affect formaldehyde emissions. This can be verified from emission testing results.[48,49] Similarly, addition of ethanol to gasoline increases ethanol and acetaldehyde exhaust emissions (as acetaldehyde is a transformation by-product of incompletely combusted ethanol).[50,51] Acetaldehyde emissions are extremely sensitive to the presence of ethanol in gasoline, from both controlled and uncontrolled vehicles (more so than formaldehyde to M*t*BE s presence). Emission tests comparing M*t*BE to ethanol-blended fuels indicate that acetaldehyde emissions may increase by 50% or greater in controlled vehicles and by as much as 150% in an uncontrolled vehicle.[52,53,54]

An earlier NESCAUM study used the Complex Model to compare emissions from an M*t*BE blend (at 11 volume percent) to those from an ethanol blend (at 5.7 volume percent). The findings supported an increase in per-mile acetaldehyde emissions ranging from 50 to 70 percent, which seems consistent with exhaust test data mentioned above. The same analysis predicted a smaller increase in per-mile benzene emissions, together with decreases in per-mile emissions of M*t*BE, formaldehyde, 1,3-butadiene and polycyclic organic matter (POM) such that the net result was a very slight (1 percent) reduction in direct toxic emissions (on a mass basis) for ethanol vs. M*t*BE-blended RFG.

Despite earlier objections regarding the insensitivity of the Complex Model to NOx emissions, NESCAUM must temporarily rely on Complex Model runs to determine changes in VOC and toxic exhaust emissions due to a M*t*BE/ethanol oxygenate switch. Although this is not an appropriate use of this tool in the case of hydrocarbons, it is currently the best way to predict any VOC changes that will occur, especially when determining toxic emission effects. It bears repeating that the Complex Model is a tool developed to determine regulatory compliance, not emission inventories. This point emphasizes the need for more sophisticated modeling techniques for emission inventory development so that the Complex Model will not have to be used in a function for which it was not intended.

As discussed in the previous section, the §202(l) rule establishes a new baseline for toxic air pollutants, such that refineries or importers of gasoline, must not exceed a 1998-2000 exhaust baseline for both RFG and CG. These anti-backsliding provisions guarantee that historic overcompliance with gasoline toxic standards, on a national average, will not slip, due to a substitution of ethanol for M*t*BE. The concern addressed by this new rule is the fear that more toxic constituents (e.g., aromatics and olefins rather than alkylates) could be used to make up the volume (and octane) shortfall caused by substituting an 11 volume percent M*t*BE blend with a 5.7 volume percent ethanol blend.[55,56] Alkylates and ethanol are already more expensive than other, more toxic gasoline constituents and, with the issuance of this rule, the demand for both is likely to grow substantially in the event that M*t*BE use is curtailed. The rule specifically guarantees overcompliance on a national average, which indicates that regionally distributed gasoline may have higher concentrations of toxic constituents as long as these are offset by gasoline with lower concentrations elsewhere in the country. Therefore, despite these gasoline toxics anti-backsliding measures, NESCAUM remains concerned that this rule does not adequately protect individual regions from increases in toxic constituents of gasoline.

### E.2  Changes in Evaporative Hydrocarbon Emissions

The potential for changes in evaporative emissions due to the large-scale replacement of M*t*BE with ethanol is likely to be more significant than the potential for changes in tailpipe emissions and is, unfortunately, more difficult to quantify. This is because the evaporative impacts of concern are indirect and may not be captured by the performance requirements of the RFG program itself. Those performance requirements will, of course, continue to apply and will largely preclude any direct RVP increases in ethanol-blended RFG. Nevertheless, the large-scale replacement of M*t*BE with ethanol in Phase II RFG could impact overall evaporative emissions—especially for vehicles that are not yet equipped with sophisticated vapor recovery systems—in the following ways:

1.  By increasing the use of ethanol in conventional gasoline markets (for reasons discussed in Section C of this chapter) where E10 blends may be eligible for a 1 psi RVP waiver;

2.  By raising overall volatility when non-ethanol blends are inadvertently commingled with ethanol blends in vehicle fuel tanks;

3.  By increasing fuel permeation through fuel lines and hoses in older vehicles and potentially impairing the performance of onboard vapor recovery systems in newer vehicles; and

4.  By enhancing the relative volatility of benzene through the formation of benzene-ethanol azeotropes.

Before examining each of these issues, it is useful to review the evaporative properties of ethanol, generally, and its effects on overall volatility when blended in gasoline. As noted previously, ethanol is unlike M*t*BE inasmuch as adding even small amounts of ethanol will raise the overall

volatility of gasoline by about 1 psi. These volatility effects are non-linear with the amount of ethanol added; RVP increases rapidly even at relatively low volumes of ethanol (i.e., up to 2.5 volume percent) and levels off (in some cases even declining slightly) when ethanol content exceeds 5 percent. Figure II-3 charts the RVP impacts of blending different fractions of ethanol and M*t*BE in a particular base gasoline (Indolene HO III). At just 5 volume percent ethanol, RVP increases from 9.0 psi to just over 10 psi. Though the initial RVP of this particular base gasoline is higher than would be allowable for Phase II RFG, the magnitude and trajectory of volatility impacts associated with adding ethanol is similar across a variety of base gasolines.

**Figure II-3**   RVP effects of ethanol and M*t*BE.[57,58]



VOLUME % OXYGENATE IN GASOLINE
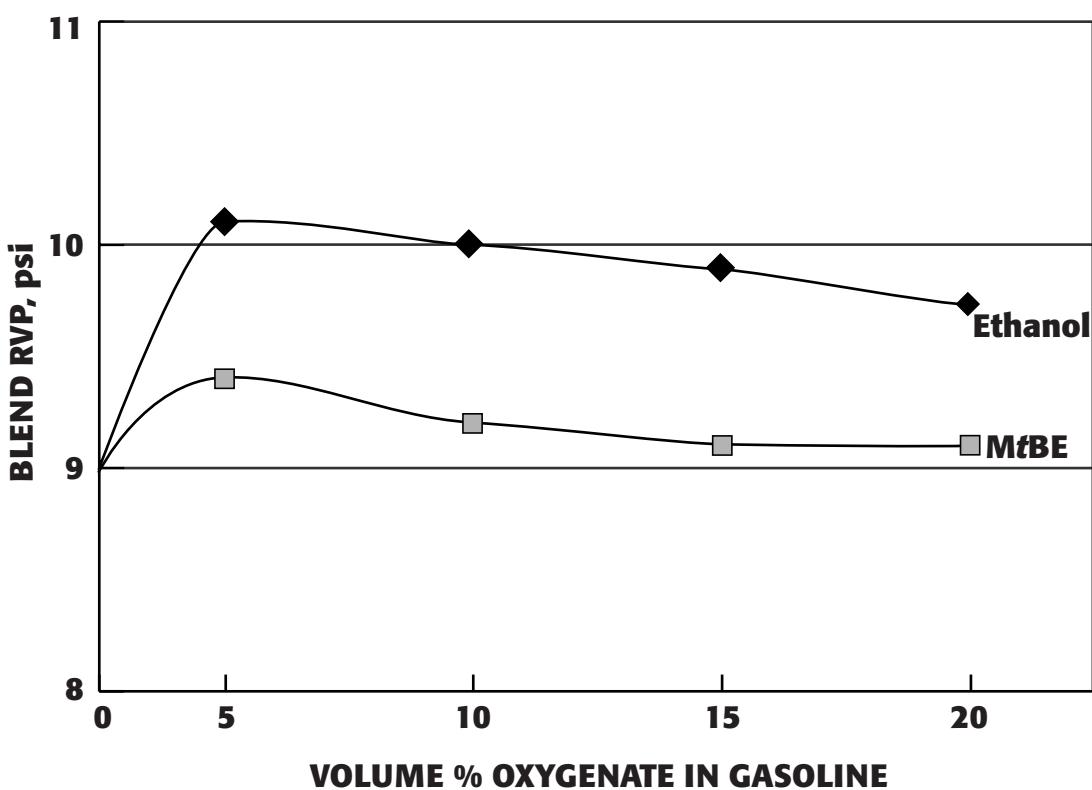
*Note:* Base gasoline – Indolene HO III

At the 5.7 percent by volume necessary to meet RFG oxygen weight requirements, ethanol causes RVP increases ranging from 1.0 to 1.2 psi, depending on the specific formulation of the blend stock. At least within the RFG program, refiners will have to compensate for this effect by formulating a lower-RVP blendstock. (It has been estimated that in the summertime, a base gasoline with RVP as low as 5.5 to 5.7 psi may be needed to allow ethanol-blended RFG to meet the 27.5 percent Phase II VOC reduction requirements).[59] However, to the extent that curtailing M*t*BE use in RFG and CG leads to the increased use of ethanol in conventional gasoline, evaporative emissions in non-RFG areas may increase, particularly in cases where ethanol-blended conventional gasoline is eligible for an RVP waiver.

A related problem is that of inadvertent commingling of ethanol and non-ethanol blended gasolines in automobile fuel tanks. Ethanol-blended RFG can be formulated to meet stringent RVP limits, but if even a small amount of it is subsequently mixed with a gasoline that is not similarly

formulated for low RVP, the volatility of the overall mixture will increase. This would be the case, for example, if ethanol-blended RFG and MtBE-blended RFG (which does not require similar RVP adjustments) were inadvertently mixed in a vehicle fuel tank.

The potential impacts of commingling have been explored in a number of studies. For example, the Energy and Environmental Research Center at the University of North Dakota recently measured the RVP characteristics of a series of mixtures composed of non-ethanol gasoline and E10 blends.[60] The unpublished results confirm that commingling does increase RVP and evaporative hydrocarbon emissions. RVP increases were most pronounced when E10 blends constituted 5 to 35 percent of the overall mixture; they were less pronounced when the ratio of E10 blends to non-ethanol blended gasoline exceeded 50 percent. Gasoline with an overall ethanol content of 2 percent by volume (achievable, for example, by mixing 20 percent E10 blends with 80 percent non-ethanol blended gasoline) showed RVP increases ranging from 0.66 to 0.93 psi over the base fuel RVP. According to the Complex Model, an RVP increase of 0.93 psi would result in a 14 percent increase in VOCs, primarily from increased evaporative hydrocarbon emissions, for a typical summertime fuel in the Northeast.

Ultimately, the emissions impacts associated with inadvertent commingling will depend on the extent to which this actually occurs. Unfortunately, that is much harder to estimate. The California Air Resources Board's (CARB) assessment of air quality impacts cites a 1994 study by Caffrey and Machiele which estimated that the aggregate impact of commingling could increase RVP by 0.1 to over 0.4 psi "depending on assumptions for the market share of ethanol-containing gasolines, consumers' brand loyalty, and the distribution of fuel tank levels before and after refueling events."[61] Caffrey and Machiele further concluded that RVP increases from commingling approach a maximum when the market share for ethanol blends reaches 30 to 50 percent, and decline thereafter as ethanol blends account for larger market shares. The extent to which these estimates are applicable to the Northeast context is an open question. California assumed that commingling effects in that state would be at the lower end of the above-referenced range; to compensate for these effects, California's RFG regulations require a 0.1 psi RVP decrease and call for further research into the commingling issue. Another potential solution to the commingling problem involves the seasonal separation of ethanol and non-ethanol fuels. For example, the use of ethanol-based fuels could be restricted to the wintertime when RVP limits are relaxed and evaporative emissions are less pronounced due to colder weather. Alternatively, or in addition, restrictions could be placed on refiners' ability to sell both ethanol-blended and non-ethanol blended gasolines (whether RFG or conventional) over a given timeframe in a given market.[62] Meanwhile, the potential for commingling must be further examined in the Northeast context; particularly where areas using ethanol-blended RFG may be adjacent either to areas that are still using MtBE-blended RFG or to conventional gasoline markets. CARB is currently conducting a study of commingling that is expected to be completed by the year's end.

The impact of such changes in fuel volatility may eventually be limited, of course, by the advent of advanced vehicle-based evaporative control systems. New on-board vapor recovery (ORVR) systems use carbon canisters to trap vapors from the fuel tank and are extremely effective at reducing evaporative emissions, achieving removal efficiencies as high as 98 percent.[63] Such systems were introduced on new vehicles starting in 1998, but are not expected to fully penetrate the Northeast fleet until 2014, as much as a decade after some states hope to begin phasing out MtBE.[64]

On board vapor recovery systems may not completely eliminate increases in evaporative emissions, as ethanol blends may produce a modest increase in evaporative emissions outside the fuel tank—for example, from lines and hoses and from the engine crankcase. Ethanol molecules not only evaporate more readily than other fuel constituents, they are relatively small and hence more easily permeate rubber, plastics, and other materials found in components of the fuel delivery system. It is thought that aromatic compounds present in gasoline may increase the solubility of rubber and plastic fuel system components to ethanol, thus providing a route for

ethanol evaporative emissions, especially in older vehicles in which these components are less resistant to ethanol diffusion.[65] This may explain why SHED tests[66] conducted in one study measured hot soak evaporative hydrocarbon emissions (1995 model year car with on-board vapor recovery) at 0.6 grams per test using 10 percent ethanol-blended CG compared to just 0.3 grams per test using 11 percent M*t*BE-blended CG (see Table II-3). Of course, both results represent a very substantial reduction from the 16.2 gram per test hot soak emissions typical of a car without on-board vapor recovery. As with the study on commingling, CARB is making an effort to understand the full extent of permeation effects on evaporative emissions. (This study is expected to be completed by spring, 2002.)

Finally, a related and perhaps more important issue concerns the potential for ethanol blends to degrade the performance of the actual ORVR system. Specifically, it has been suggested that ethanol blends could reduce the working capacity of the carbon canisters used in these systems because of ethanol's propensity to be tightly held by activated carbon and its tendency to attract water. Activated canisters are designed to capture VOC vapors from the engine fuel tank, and purge them into the air intake manifold during engine operation. However, if saturated, the canister will vent excess VOCs to the atmosphere. Oxygenates (such as ethanol and M*t*BE) bind more tightly to the activated carbon than lighter hydrocarbons. Once captured by the activated carbon, the oxygenate may then bind with water, which has been proven to reduce the working capacity of onboard vapor recovery systems. This potential for oxygenates to reduce the working capacity of the ORVR system needs further research.[67]

**Table II-3**   Removal efficiencies of one onboard vapor recovery system when operated on different blends of gasoline.[68]

| FUEL | RFG BASE | RFG OXYGENATED WITH M*t*BE | RFG OXYGENATED WITH ETHANOL |
|---|---|---|---|
| **Onboard vapor recovery removal efficiency** | 98.7 % | 97.6 % | 96.3 % |

A final area of concern with regard to potential changes in evaporative emissions concerns ethanol's specific impact on the volatility of benzene, one of the most hazardous air pollutants associated with gasoline and a known human carcinogen. In laboratory settings, the combination of ethanol and benzene has been shown to form an azeotrope (i.e., a mixture of two or more substances that retains the same composition as it moves from the liquid state to a vapor state).[69] The ethanol-benzene azeotrope is characterized by a lower boiling point and increased vapor pressure—which means it evaporates more readily than either ethanol or benzene on their own.[70,71] CARB has identified this as a potential problem, though there is still uncertainty over whether the combination of ethanol and benzene in gasoline would produce results comparable to those that have been demonstrated in the laboratory. Some evaporative emissions tests have indicated an increase in benzene emissions from ethanol-blended gasoline, but—given the many constituents of gasoline and the variety of mixtures it entails—further research is needed to establish that this would be a consistent result.[72,73,74,75] For example, other constituents of gasoline may preferentially bind with ethanol, thus out-competing benzene for azeotrope formation.

### E.3 Emissions Impacts Associated with the Production and Transport of Ethanol

A final category of emissions impacts associated with the wide-scale use of fuel ethanol in the Northeast arises from the need to produce and transport ethanol. The production of ethanol from corn or other biomass feedstocks will result in NOx and other pollutant emissions. These impacts may become important at a local or regional level if significant ethanol production capacity is

eventually developed within the Northeast. At present, however, almost all ethanol production capacity is located in Midwest, hence the greater near-term concern is emissions impacts associated with the transport of ethanol from those production centers to gasoline distribution terminals in the Northeast. As discussed further in Chapter IV, it is unlikely that substantial quantities of ethanol can be shipped to the Northeast via pipeline in the near term. Instead, transporting ethanol to northeastern distribution centers will likely involve additional freight movements by truck, barge, and possibly rail. Using very rough estimates developed in Chapter IV, transporting 670 million gallons of ethanol per year (or 15.9 million barrels) could require as many as 23,900 miles of barge travel per year and as many as 2.0 million miles of tanker truck travel *within the NESCAUM region*.[76] To calculate resulting emissions we assume the following emissions rates:

▲     **For barges –** NOx = 12 g/kw-h; HC = 0.5 g/kw-h

▲     **For tanker trucks –** NOx = 12 g/mi; HC = 4 g/mi

Assuming a 9,000 hp engine size for barges, a load factor of 0.3 and travel at 12 miles per hour, the emissions associated with 23,900 miles of barge travel per year work out to roughly 53 tons per year of NOx and 2.1 tons per year of hydrocarbons.[77] For 3 million miles of tanker truck travel, NOx emissions work out to 26 tons per year and hydrocarbon emissions work out to 8.7 tons per year at the above emissions rates.[78] Adding estimates for truck and barge emissions yields a total of 79 tons per year or about 0.22 tons per day for NOx emissions and 10.9 tons per year or about 0.03 tons per day of hydrocarbon emissions. By comparison, total daily NOx and hydrocarbon emissions from heavy-duty diesel engines in the NESCAUM region are about 550 tons and 150 tons per day, respectively. This suggests that additional emissions from barge and truck transport of ethanol in the NESCAUM region would add only about 0.04 percent and 0.02 percent, respectively, to the region's overall NOx and hydrocarbon inventories for heavy-duty engines. Interestingly, this result is quite similar to one obtained by the state of California, which estimated that the increase in emissions associated with transporting Midwestern ethanol to two central distribution locations and then trucking it to 64 storage terminals would add about 0.06 percent to the state's existing inventory of heavy duty truck emissions.

Though the above estimates are highly imprecise, they suggest that the transportation of ethanol by truck or barge within the Northeast is unlikely to have a major impact on existing criteria pollutant emission inventories at the state or regional level. Of greater concern may be the local emissions increases associated with increased truck or barge traffic at particular ports or distribution terminals.

## CHAPTER II ENDNOTES

[1] The economic impacts associated with these issues are discussed in Chapter IV.

[2] Owen, K., Coley, T. (1995) Automotive Fuels Reference Book, 2nd Edition, Society of Automotive Engineers, Inc.. Warrendale, PA., p. 85.

[3] The compliance season differs according to periods of CO concentrations in a given nonattainment or maintenance area.

[4] New York City currently complies with the CO NAAQS (65 FR 20909, April 19, 2000); accordingly New York and New Jersey are petitioning EPA to redesignate the NYC CMSA as in attainment for CO.

[5] ASTM specifications are developed with input from automobile manufacturers, gasoline refiners, end-users and other stakeholders such as governmental regulators.

[6] Downstream Alternatives, Inc. (1996) "Changes in Gasoline III, 1996 Update" Bremen, Indiana, p. 3.

[7] To optimize efficiency and engine performance, the spark that ignites the fuel-air mixture in the cylinder must be timed to occur when the piston approaches its highest point, or "top dead center." The end of the power stroke occurs when the piston reaches its lowest point, or "bottom dead center." An engine's compression ratio is measured by dividing the volume of the cylinder when the piston is at bottom dead center to its volume when the piston is at top dead center. A higher compression ratio is indicative of better thermal efficiency and results in better fuel economy and power for a given-sized engine. However, because it also means that the fuel-air mixture in the cylinder is under greater pressure as the piston approaches top dead center, a higher compression ratio also increases the tendency of the fuel to ignite prematurely, causing engine knock. For further discussion see Owen, K., Coley, T. 1995. Automotive Fuels Reference Book, 2nd Edition, Society of Automotive Engineers, Inc., Warrendale, PA. p.92.

[8] Single bond, straight chain hydrocarbons within the paraffin family are low in octane and therefore have the least resistance to knock. By comparison, branched chain compounds (also paraffins) and olefins (straight chain compounds with a double bond) are more resistant to knock. Similarly, saturated cyclic compounds have higher octane than their straight chain counterparts do. Aromatic compounds, hydrocarbons consisting of six carbons arranged in a ring, have still higher resistance to knock and are therefore high in octane; unfortunately, they tend to be among the more toxic constituents of gasoline.

[9] Downstream Alternatives, Inc. (1996) "Changes in Gasoline III, 1996 Update" Bremen, Indiana, p. 5.

[10] It must be noted that other measures are used to determine fuel volatility effects on vehicle performance, such as T10, T50 and T90 (the temperatures at which 10%, 50% and 90% of gasoline is evaporated using the ASTM D 86 Distillation test method. For further information see Owen, K., Coley, T. (1995) Automotive Fuels Reference Book, 2nd Edition, Society of Automotive Engineers, Inc., Warrendale, PA.

[11] NESCAUM (1998) RFG/MTBE Findings and Recommendations. August. p. 8.

[12] 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.

[13] There is no NOx reduction element in the original CAA RFG program. The Phase II NOx reduction requirement was added by EPA under its general authority.

[14] Including Hartford, New Britain, Middletown, New Haven, Meriden, and Waterbury.

[15] The New York City CMSA area includes parts of Connecticut and northern New Jersey.

[16] The voluntary RFG areas in the NESCAUM region include the entire states of Connecticut, Massachusetts, New Jersey and Rhode Island, and portions of New Hampshire and New York. Certain portions of Maine had voluntarily opted into the RFG program, but have since withdrawn their participation.

[17] See 62 FR 54552 (October 20, 1997).

[18] Until December 31, 1997, compliance with the Phase I federal RFG requirements was demonstrated using the "Simple Model," a spreadsheet tool that calculates the comparative emissions characteristics of different gasoline formulations based on a number of input parameters, thereby avoiding the expense of actual vehicle testing. Since 1998, the more sophisticated "Complex Model" has been used in compliance determinations. The Complex Model actually consists of two models, each of which has a number of submodels to account for geographic area and season. Distinct versions of the Complex Model are used to demonstrate compliance with Phase I and Phase II RFG requirements. The most important differences between these two versions are: (a) each relies on a different version of the MOBILE emission model for the derviation of a 1990 emission baseline, (b) light-duty trucks are not accounted for in the Phase I model, and (c) each incorporates different assumptions about high emitters and inspection and maintenance programs. In addition, the Complex Model not only quantifies the effects of oxygen, benzene, aromatics and RVP on emissions, but also estimates the effect of olefin and sulfur content as well as evaporative characteristics at high temperatures (200° and 300° F). Both models can be downloaded from the US EPA website: www.epa.gov/otaq/rfg.htm#models.

[19] Excerpted from the U.S. Environmental Protection Agency website: www.epa.gov/otaq/rfgmap.jpg. January 20, 2001.

[20] Importantly, the Complex Model does not predict either individual vehicle emissions or fleet emissions.

[21] Based on Complex Model compliance determinations. See Footnote 20.

[22] National Blue Ribbon Panel on Oxygenates in Gasoline. Final Report. August 1999.

[23] Data are derived from, EIA Petroleum Marketing Annual, 2000. Table 48 Prime Supplier Sales Volumes of Motor Gasoline by Grade, Formulation, PAD District and State.

www.eia.doe.gov/pub/oil_gas/petroleum/data_publications/petroleum_marketing_annual/current/pdf/pmtab48.pdf

[24] 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).

[25] Most methanol is produced from natural gas, though it could also be produced from other fossil fuels and woody biomass feedstocks. Methanol is relatively inexpensive—in fact, MTBE is produced from methanol—but it is toxic and highly reactive (i.e., corrosive) at higher concentrations.

[26] Current production capacity for TBA would be inadequate to supply even the Northeast market alone.

[27] For this reason, the emphasis of this report is on the specific health and economic impacts of ethanol. As noted in the introduction, if other alternatives to MTBE emerge as likely substitutes due to a change in the policy landscape or other factors, further analysis would be necessary to evaluate those alternatives.

[28] Please see discussion in Chapter 3 in companion NEIWPCC report (Volume 3).

[29] Gasoline sold in any area that requires neither oxygenated gasoline nor reformulated gasoline is termed "conventional gasoline." Conventional gasoline (CG) is subject to less stringent requirements, though it too must meet summertime RVP limits and will be regulated for sulfur content beginning in 2004. The quality of CG is protected, to an extent, by the "anti-dumping"

provisions of the RFG program. These stipulate that the average per gallon emissions of specified pollutants from CG must not deteriorate relative to emissions from a refiner's individual 1990 baseline gasoline. The anti-dumping requirements apply to all conventional gasoline producers and importers whether or not they produce or import reformulated gasoline. Because the baseline is 1990, however, existing anti-dumping provisions do not protect against the loss of any emissions improvements achieved by CG over the last decade.

[30] At 10 percent ethanol by volume, oxygenate content is 3.5 percent by weight.

[31] RVP waivers are granted only in conventional gasoline areas and usually allow a 1 psi increase in RVP. Ten percent ethanol blends are eligible for another kind of waiver that allows them to be marketed by retailers as gasoline (rather than as "gasohol"). This labeling waiver defines gasohol as substantially similar to certification gasoline (see 43 FR 24131, June 2, 1978).

[32] The Federal excise tax exemption for ethanol is currently $0.53 per gallon and is scheduled to drop to $0.52 on January 1, 2003, $0.51 on January 1, 2005 and expire on December 31, 2006.

[33] The volume gap is based on subtracting 5.7 percent (the volume of ethanol required to meet the oxygen mandate) from 11 percent (the volume of MTBE generally present in today's RFG). The exact octane gap that would result from this substitution varies depending on the specific formulation of the overall blend; hence 1.5 is an approximation. (Note that if ethanol replaces MTBE at 10 percent by volume, there would be no need to compensate for a net octane loss.)

[34] Alkylates are produced in a refinery's alkylation unit; they contain no olefins, have high octane ratings (ranging from 94 to 100), and produce relatively low emissions of hazardous air pollutants. Alkylates include branched alkanes and cycloalkanes, mostly with six to nine carbons, such as iso-octane (2,2,4-trimethylpentane) and methylcyclopentane. Alkylate production at East Coast and Gulf Coast refineries is currently close to capacity. Hence, it would take a number of years for refineries to build or modify facilities to produce enough alkylates to replace the volume and octane lost if MTBE is phased out of gasoline.

[35] The AQIRP was initiated in 1989 by 14 oil companies and 3 domestic, US, automakers. The process culminated in a final report published in January 1997. In total, over 5000 emission tests were conducted in over 100 vehicles using over 90 fuel compositions.

[36] In the cases where ethanol is examined as a gasoline oxygenate, it was blended at a broad range of volumes, from 5% to 15% of the volume of fuel tested, adding yet another level of variability in the tests.

[37] Knapp, K.T., Stump, F.D., Tejada, S.B. (1998) The Effect of Ethanol Fuel on the Emissions of Vehicles over a Wide Range of Temperatures. Journal of the Air and Waste Management Association, Vol. 48, July.

[38] Knepper, J., Koehl, W.J., Benson, J.D., Burns, V.R. Gorse, R.A., Hochhauser, A.M., Leppard, W.R., Rapp, L.A., Reutor, R.M. (1993) Fuel Effects in Auto/Oil High Emitting Vehicles. SAE Document No. 930137, March.

[39] US Environmental Protection Agency (2001) Technical Support Document Analysis of California's Request for Waiver of the Reformulated Gasoline Oxygen Content Requirement for California Covered Areas. EPA-420-R-01-016, pg. 22, June.

[40] Lindhjem, Christian E. EPA Memorandum to Richard Rykowski Effects of Oxygenates on Emissions, January 7, 1992. [R0319]

[41] National Science and Technology Council. Committee on Environment and Natural Resources, Interagency Assessment of Oxygenated Fuels. June 1997. [R2482] www.epa.gov/oms/regs/fuels/ostpfin.pdf.

[42] Reuter, R.M., Benson, J.D., Burns, V.R., Gorse, R.A., Hochhauser, A.M., Koehl, W.J., Painter, L.J., Rippon, B.H., Rutherford, J.A. (1992) Effects of Oxygenated Fuels and RVP on Automotive Emissions - Auto/Oil Air Quality Improvement Program. Auto Air Quality Improvement Research Program, SAE 920326, SAE International, Warrendale, PA.

[43] National Science and Technology Council. Committee on Environment and Natural Resources, Interagency Assessment of Oxygenated Fuels. June 1997. [R2482] www.epa.gov/oms/regs/fuels/ostpfin.pdf.

[44] Newkirk, M.S. (1997) Emissions Characterization of Baseline Gasoline and Gasoline/Oxygenate Blends Under Tier 1 of the CAA 211(B) Fuels and Fuel Additives Registration Regulations. American Petroleum Institute, May.

[45] Knapp, K.T., Stump, F.D., Tejada, S.B. (1998) The Effect of Ethanol Fuel on the Emissions of Vehicles over a Wide Range of Temperatures. Journal of the Air and Waste Management Association, Vol. 48, July.

[46] Newkirk, M.S. (1997) Emissions Characterization of Baseline Gasoline and Gasoline/Oxygenate Blends Under Tier 1 of the CAA 211(B) Fuels and Fuel Additives Registration Regulations. American Petroleum Institute, Washington, DC.

[47] Stump, F.D., Knapp, K.T., Ray, W.D. 1996. "Influence of Ethanol-Blended Fuels on the Emissions from Three Pre-1985 Light-Duty Passenger Vehicles," Journal of the Air and Waste Management Association, Vol. 46, December.

[48] Newkirk, M.S. (1997) Emissions Characterization of Baseline Gasoline and Gasoline/Oxygenate Blends Under Tier 1 of the CAA 211(B) Fuels and Fuel Additives Registration Regulations. American Petroleum Institute, Washington, DC.

[49] Stump, F.D., Knapp, K.T., Ray, W.D. (1990) Seasonal Impact of Blending Oxygenated Organics with Gasoline on Motor Vehicle Tailpipe and Evaporative Emissions. Journal of the Air and Waste Management Association, Vol. 40, No. 6, June.

[50] Newkirk, M.S. (1997) Emissions Characterization of Baseline Gasoline and Gasoline/Oxygenate Blends Under Tier 1 of the CAA 211(B) Fuels and Fuel Additives Registration Regulations. American Petroleum Institute, Washington, DC.

[51] Knapp, K.T., Stump, F.D., Tejada, S.B. (1998) The Effect of Ethanol Fuel on the Emissions of Vehicles over a Wide Range of Temperatures. Journal of the Air and Waste Management Association, Vol. 48, July.

[52] Newkirk, M.S. (1997) Emissions Characterization of Baseline Gasoline and Gasoline/Oxygenate Blends Under Tier 1 of the CAA 211(B) Fuels and Fuel Additives Registration Regulations. American Petroleum Institute, Washington, DC.

[53] Knapp, K.T., Stump, F.D., Tejada, S.B. (1998) The Effect of Ethanol Fuel on the Emissions of Vehicles over a Wide Range of Temperatures. Journal of the Air and Waste Management Association, Vol. 48, July.

[54] Stump, F.D., Knapp, K.T., Ray, W.D. (1990) Seasonal Impact of Blending Oxygenated Organics with Gasoline on Motor Vehicle Tailpipe and Evaporative Emissions. Journal of the Air and Waste Management Association, Vol. 40, No. 6, June.

[55] Importantly, refiners' need to formulate a low-RVP base gasoline to make up for the volatility effects of adding ethanol may create a further volume gap by forcing the removal of lighter hydrocarbons (such as pentanes and butanes) from ethanol blends. The RVP impacts of substituting MTBE with ethanol are discussed in greater detail in the next section.

[56] See discussion accompanying Table II-2.

[57] Furey, R.L. (1985) Volatility Characteristics of Gasoline-Alcohol and Gasoline-Ether Fuel Blends. SAE Technical Paper Series No. 852116, Warrendale, PA.

[58] Note that the RVP response of a particular blendstock of gasoline to the addition of different oxygenates is highly dependent on the constituents that make up that blend of gasoline.

[59] The cost and feasibility of achieving compliance with summertime RVP limits using ethanol-blended RFG constitute a separate concern, which is addressed in Chapter IV of this report.

[60] Aulich, T., Richter, J. (1999) Addition of Non-ethanol Gasoline to E10—Effect on Volatility. University of North Dakota Energy & Environmental Research Center, July. This analysis used gasolines with relatively high RVPs (9.85 and 9.9) compared with Northeast typical

summertime RVPs of 7.7 to 7.9, which were expected to decrease to about 6.5 to 6.7 psi in order to achieve Phase II VOC requirements in 2000.

[61] Note that commingling is an issue for California, primarily, if the state is granted a waiver from the current oxygenate requirement. If not, under California's MTBE ban, ethanol will be effectively required in some 80 percent of the California market (since most of the state is required to provide RFG). See California Environmental Protection Agency Air Resources Board, Air Quality Impacts of the Use of Ethanol in California Reformulated Gasoline: Final Report to the California Environmental Policy Council, December 1999, p. 2.

[62] Note that this would likely increase refiners' costs. For this reason, past USDOE modeling analyses have assumed that refiners would split their RFG and CG pools into ethanol and non-ethanol blends to minimize expenses. See NESCAUM (1999) An Assessment of Options for Reducing MTBE in Reformulated Gasoline, Appendix A.

[63] Newkirk, M.S. (1997) Emissions Characterization of Baseline Gasoline and Gasoline/Oxygenate Blends Under Tier 1 of the CAA 211(B) Fuels and Fuel Additives Registration Regulations. American Petroleum Institute, Washington, DC.

[64] Full penetration is defined as the time when 90% of the fleet contains the relevant control technology (in this case, on-board vapor recovery).

[65] "Concerning Evaporative Emission Effects (Permeation) Created by Ethanol in Gasoline" Harold Haskew and Associates, May 31, 2001.

[66] SHED (Sealed Housing for Evaporative Determination) tests refer to a type of emissions test in which measurements are taken of the total evaporative emissions given off as a hot engine is allowed to cool in a sealed chamber.

[67] California Air Resources Board (1999) Health and Environmental Assessment of the Use of Ethanol as a Fuel Oxygenate. Vol. 3, UCRL-AR-135949 Vol. 3, p. 19.

[68] Derived from data generated by the study referenced in footnote 64.

[69] In simple terms, an azeotrope is a mixture of two or more chemicals that physically behaves as one. Once the constituents are mixed, the mixture acts as a completely new substance with new physical characteristics, such as boiling temperature and vapor pressure. Thus, the constituents of an azeotrope, as a mixture, cannot be separated by simple distillation.

[70] Ethanol actually forms a ternary azeotrope with benzene and water. The boiling point of this azeotrope is 64.9°C (or 148.8°F). By comparison, the boiling point of neat benzene is 80°C (176°F), the boiling point of neat ethanol is 78.5°C (173°F) and the boiling point of neat water is 100°C (212°F). Ethanol also forms a binary azeotrope with water, which prevents the manufacture of 100% pure ethanol from a simple distillation process. In the past, a benzene extraction process was used to dehydrate the ethanol-benzene azeotrope, however molecular sieve techniques to purify ethanol have replaced this method.

[71] Morrison and Boyd (1983) Organic Chemistry, 4th Edition, Allyn and Bacon, Inc., p. 464. Newton, MA.

[72] Available studies suggest that the addition of ethanol can significantly increase hot soak benzene emissions (one study using an E10 blend showed a forty five percent increase in evaporative benzene emissions relative to non-ethanol blended gasoline).

[73] Reuter, R.M., Benson, J.D., Burns, V.R., Gorse, R.A., Hochhauser, A.M., Koehl, W.J., Painter, L.J., Rippon, B.H., Rutherford, J.A. (1992) Effects of Oxygenated Fuels and RVP on Automotive Emissions - Auto/Oil Air Quality Improvement Program. Auto Air Quality Improvement Research Program, SAE 920326, SAE International, Warrendale, PA.

[74] Newkirk, M.S. (1997) Emissions Characterization of Baseline Gasoline and Gasoline/Oxygenate Blends Under Tier 1 of the CAA 211(B) Fuels and Fuel Additives Registration Regulations. American Petroleum Institute, Washington, DC.

[75] Stump, F.D., Knapp, K.T., Ray, W.D. (1990) Seasonal Impact of Blending Oxygenated Organics with Gasoline on Motor Vehicle Tailpipe and Evaporative Emissions. Journal of the Air and Waste Management Association, Vol. 40, No. 6, June.

[76] Note that this very rough estimate does not include transport from the Midwest to the NESCAUM region, which may also be of concern with respect to the long-range transport of NOx and particulate matter. The estimate for barge miles assumes that all 15.9 million barrels of ethanol enter the Northeast at Philadelphia (currently the case for much of the ethanol used by Getty, a gasoline retailer that is already using ethanol in Northeast markets). It further assumes that 30% of the region's total ethanol demand is transported 100 miles by barge from Philadelphia to ports in the New York City area, another 40% is transported 300 miles by barge to the Boston area, and another 30% serves New Jersey and does not need to be transported by barge beyond Philadelphia. Assuming 100,000 barrels are transported in each barge trip (see discussion in Chapter IV), the estimate for total barge travel is calculated as follows: [(15,900,000 bbl x 0.3 x 100 miles) + (15,900,000 bbl x 0.4 x 300 miles)]/[100,000 bbls] = 23,934 miles.

Given the uncertainties in this estimate, the figure is rounded down to 23,900 miles. To generate a rough estimate of travel by tanker truck we assume that, on average, each barrel of ethanol will need to be transported an additional 25 miles to a distribution terminal. Obviously, actual transport distances will be much greater in some cases and less in others. Using a tanker truck capacity of 200 barrels (see Chapter IV), the calculation is: 15,900,000 bbls x 25 miles x 1/200 bbls = 1.99 million miles. Round this up to 2.0 million miles.

[77] The calculation is as follows:

[9000 hp x 0.7457 kw/hp x 0.3 (load factor) x (23,900 mi/12 mph) x 12 g/kwh x 0.035 oz/g x1 lb/16 oz x 1 ton/2000 lb] = 52 tons. For HC, we simply take the result for NOx and multiply by the ratio of the two emissions factors (0.5/12).

[78] The calculation for NOx is: 2,000,000 mi x 12.1 g/mi x 0.035 oz/g x 1 lb/16 oz x 1 ton/2000 lb = 26 tons. The calculation for HC is 2,000,000 mi x 4 g/mi x 0.035 oz/g x 1 lg/16 oz x 1 ton/2000 lb = 8.7 tons.

# CHAPTER III

# HEALTH IMPACTS ASSESSMENT

## A. INTRODUCTION

*G*asoline is a complex mixture containing hundreds of compounds, many of which are known or suspected human carcinogens and/or contribute to ozone and fine particulate matter formation, as well as water pollution. The combustion of gasoline produces emissions of volatile organic compounds (VOCs), many of which are considered hazardous air pollutants (HAPs), as well as a range of pollutant by-products that are directly or indirectly harmful to human health, including carbon monoxide (CO) and oxides of nitrogen (NOx). VOCs and NOx contribute to the formation of ground-level ozone and fine particle matter, both of which are linked to a variety of adverse human health impacts. Table III-1 lists the major gasoline constituents of concern, including aromatics, oxygenates and combustion by-products.[1] Benzene and the combustion by-products acetaldehyde, acrolein, 1,3-butadiene and formaldehyde are classified as known or suspected human carcinogens.[2] In addition to their potential cancer-causing effects, gasoline constituents also cause adverse non-cancer health effects, such as respiratory irritation, exacerbation of asthma symptoms, damage to the liver or kidney, alterations in the function of the central nervous system, and—in cases where a pregnant woman is exposed—neurological damage to the developing fetus. In short, all gasoline formulations—whether conventional or reformulated and oxygenated or non-oxygenated—present cancer and non-cancer health hazards when individuals are exposed to sufficient concentrations of their toxic constituents.

Overall, as noted in the foregoing chapters, the introduction of federal RFG has provided important benefits in terms of reducing emissions of ozone precursors and certain toxic pollutants; however, the adverse water quality impacts associated with the increased use of M*t*BE have led to questions about the merits of this program.[3] The broader health impacts associated with the RFG program generally and with the use of M*t*BE specifically are detailed in a number of earlier NESCAUM studies.[4]

In 1999, NESCAUM conducted an analysis of the potential risks associated with multi-media exposure to M*t*BE. The analysis summarized the existing state of knowledge regarding the cancer and non-cancer health effects of M*t*BE and other gasoline constituents, provided a cumulative exposure analysis of M*t*BE releases to the environment, and qualitatively evaluated the potential toxic effects of M*t*BE alternatives, including ethanol. The following evaluation builds upon this analysis by focusing on the potential health impacts from the use of ethanol as an alternative to M*t*BE in reformulated gasoline in the Northeast.[5]

To evaluate the potential multi-media health impacts associated with the large-scale use of ethanol in Northeast fuel, three categories of potential impact must be assessed. The first relates to the potential for increased exposure to ethanol and its immediate by-products (primarily acetaldehyde). A second category of potential public health impacts relates to any changes in ambient air quality that are expected to occur because of direct changes in toxic emissions that occur from different fuel formulations and indirect emission associated with the transport and storage of ethanol in the Northeast.[6] The third category

relates to the public health impacts from exposure to gasoline constituents that result from contamination of drinking water supplies. This assessment requires modeling of air quality impacts due to the introduction of ethanol into RFG, and estimates of potential groundwater and surface water impacts from ethanol-blended gasoline releases into the environment. To date, such modeling has not been performed for the Northeast[7] (though it has been done for California). Given that the underlying database for quantifying ethanol exposure is significantly limited compared to the database for M*t*BE, and that the scope of this report was limited to evaluating available studies on ethanol, only a broad and highly qualified assessment of the relevant health issues can be conducted at this time.

The companion New England Interstate Water Pollution Control Commission (NEIWPCC) report provides a comprehensive toxicity profile for ethanol that focuses on the drinking water pathway. The margin of exposure (MOE) analysis presented herein builds upon this companion report by integrating inhalation and ingestion exposure scenarios associated with the potential release of ethanol into the ambient air and drinking water. This assessment mirrors the cumulative dose approach used by NESCAUM in evaluating the multi-media nature of M*t*BE exposure in 1999.[8] This previous NESCAUM study also evaluated the potential impacts of the use of M*t*BE-blended fuel on other motor vehicle air toxics, including benzene. However, due to the paucity of modeling and monitoring data on emissions from the use of ethanol-blended fuels, the health concerns related to increases in other toxic pollutant emissions (notably acetaldehyde) and to potential changes in ambient levels of criteria pollutants are, for the most part, reviewed only qualitatively in this chapter.

Organizationally, the chapter is divided into four sections. The first section provides context for evaluating the inhalation risks associated with direct exposure to ethanol and should be viewed in conjunction with the NEIWPCC toxicity profile presented in Volume 3.[9] The second section describes a "margin of exposure" analysis for ethanol. This type of analysis aims to develop a range of plausible exposure scenarios for the inhalation and ingestion of ethanol.[10] The third section of this chapter qualitatively addresses the potential health impacts associated with direct and indirect changes in ambient air concentrations of criteria and toxic pollutants resulting from the use of ethanol-blended gasoline. Finally, section four presents the uncertainties and research recommendations that must be considered by policymakers in evaluating the public health implications of replacing M*t*BE with ethanol.

## B. POTENTIAL HEALTH EFFECTS OF ETHANOL

### B.1  Health Effects Associated with Inhalation of Ethanol

The well-established effects from ethanol ingestion summarized in the companion NEIWPCC report are not directly relevant to the health effects associated with inhalation exposures to ethanol from its use in gasoline. However, there is a significant lack of information on the health effects associated with inhalation of ethanol. For example, as part of an effort to develop allowable inhalation concentrations for ethanol in spacecraft, a comprehensive review of the available literature was conducted for the National Aeronautics and Space Administration (NASA) in 1997.[11] It found that only two human studies have been conducted to assess the toxicity of ethanol from inhalation exposure, both of which had few subjects, were uncontrolled, and relied on subjective reporting of symptoms. The primary health effects reported in these studies, which involved relatively high concentrations of ethanol, were central nervous system effects, irritation to the eyes and respiratory system, and a "flushing response" (experienced primarily by Asian subjects due to an enzyme deficiency discussed in more detail below) that is manifested by facial flushing, elevation of skin temperature, and an increase in the pulse rate.[12] Therefore, the following section discusses sensitive subpopulations that may be adversely impacted by ethanol exposure.

**Table III-1** Comparison of regulatory and health protective threshold concentrations for gasoline constituents and exhaust products.[13]

| GASOLINE CONSTITUENTS | Northeast State Drinking Water Limit (a) µg/L (ppb) | EPA Reference Concentration µg/m$^3$ [14] | EPA Reference Dose[14] µg/kg/day | Inhalation 1 in 1 million Excess Cancer Risk µg/m$^3$ (air) | Ingestion 1 in 1 million Excess Cancer Risk µg/L (ppb) (water) | Threshold Limit Value µg/m$^3$ (f) (air) |
|---|---|---|---|---|---|---|
| BENZENE | 5 | 71[15] | N/A | 0.13-0.45 | 1 – 10 | 0.0016 |
| ETHYL BENZENE | 700 | 1000 | 100 | N/A | N/A | 0.434 |
| TOLUENE | 1000 | 400 | 200 | N/A | N/A | 0.188 |
| XYLENE | 10,000 | 300[15] | 2000 | N/A | N/A | 0.434 |
| OXYGENATES: | | | | | | |
| •ETHANOL | 1.1 X 10$^6$(a) | 100,000 (b) | N/A | N/A (c) | N/A(d) | 1.884 |
| •M*t*BE* | 13 (e) | 3000 | N/A | 6[16] | 13 (e) | 0.144 |
| 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 | 0.5 | N/A | 0.045 not to be exceeded for >15 minutes |
| •ACROLEIN | N/A | 0.02 | N/A | N/A | N/A for | 0.00023 not to be exceeded >15 minutes |
| •1,3-BUTADIENE | 0.019 | 8[15] | N/A | 0.004 | N/A | 0.0044 |
| •FORMALDEHYDE | N/A | 3.6[15] | 200 | 0.08 | N/A | 0.00037 not to be exceeded for > 15 minutes |

(a) The most restrictive Northeast state drinking water standard is listed except for ethanol which is a draft Health Protective Concentration derived by California; state-by-state variation may exist in these limits.

(b) Draft California Annual Health Protective Concentration

(c) No Evidence of Carcinogenicity by Inhalation-California

(d) This table presents current regulatory guidelines. However, ethanol in alcoholic beverages is considered carcinogenic by EPA, IARC, and NTP.[17]

(e) Based on New Hampshire DES using linearized multistage modeling.

(f) Established by the American Conference for Governmental Industrial Hygienists (ACGIH)

## B.2  Sensitive Subpopulations

In general, the toxicity of ethanol is dependent on an individual's ability to metabolize and eliminate ethanol from the body. This occurs through the action of critical metabolic enzymes primarily in the liver.[18] During the process of metabolism and elimination, the body forms intermediate breakdown products, such as acetaldehyde. Many researchers believe that the toxic effects associated with ethanol exposure may be caused by ethanol and/or acetaldehyde. The expression and activity of the critical metabolic enzymes is known to vary with individual characteristics, including age, hormone levels, and dietary habits. Therefore, the formation and residence time of intermediate ethanol breakdown products will vary accordingly. The activity of critical metabolic enzymes may be subject to genetic variability as well. For instance, as noted above, differences in the oxidation of alcohol and a deficiency in aldehyde dehydrogenase (ALDH, one of the critical metabolic enzymes) have been shown to result in acetaldehyde accumulation and more pronounced symptoms of intoxication in Asian populations.[19] In fact, researchers have demonstrated a two to three-fold variability in individual rates of ethanol elimination (at identical levels of exposure) simply due to these differences in metabolic processing capacity.[20] Therefore, it is important that evaluations of the potential health effects from ethanol exposure consider subpopulations that are more sensitive to ethanol because of their deficiency in metabolizing acetaldehyde.

Froines and colleagues also raise the possibility that asthmatics with metabolizing enzyme deficiencies may be at-risk of having their symptoms exacerbated by ethanol exposure since ingestion of ethanol has long been known to provoke acute symptoms in Asian patients with asthma due to deficiency in ALDH activity.[21] The investigators concluded: "These studies raise the theoretical possibility that patients with asthma who do not metabolize acetaldehyde well, including many Asians, and patients taking captopril or disulfiram, might be at risk of asthma exacerbation after inhalation of ethanol." Although human studies have suggested that inhalation of ethanol does not pose a risk, Froines et al. also concluded that "the demonstrated direct bronchioconstrictor effect of acetaldehyde aerosol in patients with asthma, and potentiating effect of subclinical doses of acetaldehyde on bronchial hyper-responsiveness to other exposures, suggest the need for further investigation to evaluate the effect of ambient exposures on subjects with asthma."

An additional toxicological concern that should also be considered is the potential for increased *in vivo* expression of relevant metabolic enzymes across all individuals in an exposed population following repeated low-concentration exposures to ethanol. The critical enzymes involved in ethanol breakdown and elimination also serve to metabolize and eliminate a host of other toxicants. Low concentration "priming" (alteration of metabolic enzyme expression or activity) of the relevant metabolic pathways by ethanol may result in enhanced toxicity and human susceptibility to other compounds as well. For example, ethanol and other alcohols are known to potentiate the toxicity of a number of prescription medications and environmental toxicants, such as benzene, carbon tetrachloride and cadmium.[22] The impact of concurrent exposures to low-level ethanol concentrations and other toxic contaminants is not adequately understood at this time and must be more carefully evaluated given the broad exposure to low levels of ethanol that could result from its large-scale use as part of the region's fuel supply.

Finally, as noted above and discussed extensively in the NEIWPCC report, the effects of greatest concern associated with relatively low dose exposures to ethanol are neurodevelopmental deficits in the fetus. Because some of ethanol's effects on development are associated with peak blood ethanol levels and not average blood levels, it is critically important that maternal exposure to ethanol be maintained below a critical health protective level on each day of pregnancy. Given the wide range of exposures that may occur from gasoline use, research is needed to address the potential for relatively high episodic exposures (e.g., refueling) to ethanol that may exceed these health protective levels.

## C. MARGIN OF EXPOSURE ANALYSIS FOR ETHANOL USED IN MOTOR FUEL

A margin-of-exposure (MOE) analysis is a method for bounding the potential health risks from exposure to a particular substance into the environment. Margins of exposure reflect the ratio between the level associated with observed toxicity in humans or animals and estimated levels of exposure in particular situations. The MOE analysis for fuel ethanol is limited because of a significant lack of data available to evaluate the potential health effects associated with repeated exposure, via inhalation or ingestion, to environmentally relevant concentration of ethanol in air and water. Because of these data gaps, the MOE analysis presented in the next section depicts worst-case exposure scenarios associated with ethanol releases to the environment. Future research recommendations identified at the end of this chapter are aimed at providing the necessary information for refining these exposure estimates

The first step in the MOE analysis is to identify potential routes of exposure and to estimate the likely duration and frequency of discrete exposure events. The second step involves estimating the range of concentrations (in both air and water) relevant to each type of exposure. Concentration estimates can then be combined with estimates of exposure frequency and duration to estimate total exposure from multiple exposure pathways. This multi-media analysis considers exposures due to the widespread use of ethanol in gasoline, which may result in long-term (chronic) exposure to low concentrations of ethanol via inhalation, and additional episodic exposures to more elevated concentrations during certain activities (e.g., refueling). In addition, the potential for contamination of public and private water supplies is considered in the event that a fuel spill or leak results in exposure to elevated concentrations of ethanol via both inhalation and ingestion pathways. Finally, to provide context for the exposure estimates calculated in the analysis, the exposure ranges are compared to the range of endogenous blood ethanol concentrations that are produced naturally during the course of normal metabolic processes.

### C.1  Exposure Scenarios for Ethanol in Gasoline

For the MOE analysis developed below, NESCAUM constructed four multi-media exposure scenarios intended to represent low, moderate, high and extreme cases of exposure. Each scenario combines potential exposures from inhalation of contaminated air and direct ingestion of contaminated water. Specific inhalation exposures include inhalation of indoor air, inhalation of outdoor air, inhalation during refueling, and inhalation of volatilized ethanol in the shower or bath. Each of the four total exposure scenarios is based on a different assumption concerning the presence of ethanol in household water supplies. These assumptions, in turn, drive exposure from the inhalation of volatilized ethanol in the shower or bath, indoor air concentrations,[23] and direct ingestion from drinking water.

Table III-2 presents the assumptions and sources of data for estimating exposure to ethanol in this analysis. At the low end, NESCAUM assumed a water ethanol concentration of 0.058 mg/L based on measured ethanol levels in "good" quality groundwater from Yasuhara, et al. (1981).[24] The moderate value for potential water contamination is based on the draft Comparative Drinking Water Value for chronic ethanol exposure developed by Ginsberg and Chute for the companion NEIWPCC report. A similarly calculated comparative value could form the basis for future water quality standards limiting the ethanol content in drinking water. Ginsberg and Chute's draft daily comparative value of 4.0 mg/day for a 60 kg adult[25] translates into a water concentration of 0.4 mg/L assuming that the average person ingests 2 L of water per day and that exposure from drinking water accounts for 20 percent of overall exposure.[26] For the water contamination levels assumed in the high and extreme exposure scenarios, NESCAUM used reported taste thresholds for ethanol in water. To account for the possibility that an individual relying on private water supplies (outside the enforcement of any applicable water quality standards) might be unaware of contamination resulting from a nearby ethanol spill or leak unless alerted by taste, NESCAUM used the 6 mg/L value for its high exposure case and the 50 mg/L value for its extreme exposure case.[27] It should be noted that the NEIWPCC companion report identifies ethanol contamination of

drinking water as the risk scenario of greatest potential concern. Specifically, this scenario involves the possibility that pregnant women might unknowingly ingest substantial concentrations of ethanol, even for a relatively short periods of time (days to weeks), which would lead to potential pregnancy risk concerns. Because of the lack of data to adequately evaluate this scenario, NEIWPCC recommends that additional information be collected on the possibility that ethanol can reach high levels in drinking water supplies, especially in cases of large-scale releases of neat (pure) ethanol (e.g., leakage from dedicated storage tanks).

Table III-2 also shows the daily duration of exposure assumed for each exposure pathway and cites sources of data for the low and high inhalation concentrations used in the analysis. Note that the inhalation concentrations assumed for shower or bath exposures are a direct function of the ethanol concentrations assumed for household water supplies. They are calculated by assuming that the volatilization of ethanol from water in the shower or bath stall is the same as has been

| **Table III-2** Assumptions and sources of data for estimating inhalation exposures. | | | |
|---|---|---|---|
| **TYPE OF EXPOSURE** | **LOW-HIGH ETHANOL CONCENTRATION (mg/m$^3$)** | **DURATION OF EXPOSURE** | **SOURCES OF DATA** |
| **SHOWER/BATH** (Represents inhalation of ethanol volatilized to the air from contaminated water*)* | 0.332 2.29 34.32 240.21 | 0.25 hrs (15 min) | According to Wallace (1996) [28] the presence of benzene at 0.292 mg/L in shower or bath water results in surrounding air concentrations as high as 1670 g/m$^3$ (1.67 mg/m$^3$). Exposure concentrations are calculated by applying the same volatilization ratio (1.67/0.292) to the assumed low, medium, high, and extreme water ethanol concentrations (i.e., 0.058 mg/L, 0.4 mg/L, 6 mg/L and 50 mg/L, respectively). |
| **HOUSEHOLD (INDOOR) AIR** | 0.0043 – 2.59 | 15.75 hrs (945 min) | Household (indoor) air concentrations ranging from 0.5 ppb to 100 ppb were measured in Chicago and reported by Jarke, F.H., et al. (1981).[29] Concentrations in ppb (= 1/1000 ppm) are converted to mg/m$^3$ using the relationship of 1 ppm = 1.88 mg/m$^3$ reported by Andersson and Victorin (1996).[29] [0.5 ppb = 0.00094 mg/m$^3$; 100 ppb = 0.188 mg/m$^3$] Assume that 0.01 of the shower/bath concentration above are added to indoor air concentrations. |
| **REFUELING** | 1.88 – 86.5 | 0.05 hrs (3 min) | Range of refueling concentrations reported in Health Effects Institute (HEI), 1996, *The Potential Health Effects of Oxygenates Added to Gasoline: A Review of the Current Literature.* Range of concentrations reported in this review was approximately 1-46 ppm; this was converted to mg/m$^3$ using the same approach as above for household air. The high-end value is based on refueling without Stage II vapor recovery system. This is relevant to the Northeast as a number of locations in this region do not require this emission control device. |
| **AMBIENT (OUTDOOR) AIR** | 0.024 – 0.15 | 7.95 hrs (477 min) | The low value is a measured value from ambient monitoring conducted by the Wisconsin Department of Natural Resources in Milwaukee in 1997 [30] where gasohol is used. The high value is the upper bound maximum daily ambient air concentration modeled by California for 2003 CA RFG containing ethanol at 3.5 percent oxygen weight (i.e., more than the minimum 2% weight requirement or about 10 percent by volume).[31] |

measured for benzene. It should be noted, however, that Henry's law constant[32] for benzene is greater than 0.1 whereas the constant for ethanol is 0.000252. A Henry's law constant less than 0.05 indicates that volatilization from surface water and off gassing from groundwater is unlikely, and that vapor phase retardation will be high.[33] Because the air/water-partitioning coefficient for ethanol is lower compared to benzene, ethanol will tend to remain in the water phase at the standard testing temperature of 59 degrees Fahrenheit. A conservative assumption is used to estimate ethanol's volatilization during bathing because there is a lack of testing data on the volatilization of low concentrations of ethanol and because the possibility exists that ethanol would volatilize more readily at a higher water temperature. Therefore, the assumption that ethanol will volatilize like benzene represents an absolute worst case for the shower or bath scenarios evaluated herein. Table III-3 shows the specific inhalation and ingestion assumptions used to construct each total exposure scenario.

To calculate the peak blood ethanol concentration (BEC, in mg/L) associated with each inhalation exposure, NESCAUM applied the following equation:[34]

$$\frac{[\text{Exposure Conc. (mg/m}^3\text{)} \times \text{Exposure Duration (hrs)} \times \text{Ventilation Rate (m}^3\text{/hr)} \times \text{Absorption Factor (\%)}]}{[\text{Volume of distribution (L/kg)} \times \text{Body Weight (kg)}]}$$

where:
Ventilation Rate $= 0.83$ m$^3$/hr
Absorption Factor[35] $= 62\%$
Volume of distribution $= 0.7$ L/kg
Body Weight $= 60$ kg

Having calculated a blood ethanol burden from inhalation, NESCAUM calculated ingestion from contaminated drinking water, as follows:

$$\frac{[\text{Exposure Concentration (mg/L)} \times \text{Daily Ingestion (L)} \times \text{Absorption Factor (\%)}]}{[\text{Volume of distribution (L/kg)} \times \text{Body Weight (kg)}]}$$

where:
Daily Ingestion $= 2$ L
Absorption Factor $= 100\%$
Volume of distribution $= 0.7$ L/kg
Body Weight $= 60$ kg

Total blood ethanol concentrations is calculated as follows:

**TOTAL Blood Ethanol Concentrations (BEC) = BEC $_{\text{inhalation}}$ + BEC $_{\text{ingestion}}$**

| **Table III-3** Specific concentrations assumed for each exposure scenario. | | | | | |
|---|---|---|---|---|---|
| **EXPOSURE SCENARIOS** | **CONCENTRATIONS ASSUMED FOR INHALATION EXPOSURES (mg/m$^3$)** | | | | **CONCENTRATION ASSUMED FOR FOR INGESTION EXP. (mg/L)** |
| | **SHOWER/BATH** | **INDOOR AIR** | **REFUELING**[36] | **OUTDOOR AIR** | |
| **LOW** | 0.332 | 0.0043 | 1.88 | 0.024 | 0.058 |
| **MODERATE** | 2.29 | 0.21 | 86.5 | 0.15 | 0.4 |
| **HIGH** | 34.32 | 0.53 | 86.5 | 0.15 | 6 |
| **EXTREME** | 240.21 | 2.59 | 86.5 | 0.15 | 50 |

## C.2  Development of Comparative Blood Ethanol Concentrations

To provide context for the exposure values predicted in the MOE analysis discussed above comparative blood ethanol concentrations were developed based on the endogenous range of ethanol in the body from natural metabolic processes. A certain amount of ethanol is produced during normal metabolic processes as a by-product of the breakdown (or oxidation) of carbohydrates in the digestive system. Since increased exposure to ethanol as a consequence of its use in fuel could add to these endogenous blood levels, the point of comparison for the margin of exposure estimates is the range of endogenous BECs that can result from normal metabolic functioning in the human body. For this analysis, endogenous blood ethanol concentrations in humans are assumed to range from as low as 0.2 mg/L to 10 mg/L.[37] It should be noted that although exposure to relatively high levels of ethanol is required to elicit functionally significant neurodevelopmental deficits, a level of ethanol exposure above endogenous levels that is without any risk to the developing fetus has not been definitively identified.

## C.3  Results of Margin of Exposure Analysis

The total blood ethanol concentrations developed in the MOE analysis for the four scenarios are shown in Figure III-1. Figure III-1 also indicates the range of background endogenous blood ethanol concentrations of 0.2-10 mg/L.

Figure III-1 shows that the predicted blood ethanol concentrations associated with multi-media exposure to ethanol from its use in gasoline range from negligible for the low exposure scenario (<0.008 mg/L) to 4.1 mg/L for the extreme scenario. The total exposure estimates for the moderate and high exposure scenarios are 0.13 and 0.56 mg/L, respectively. The results from the MOE analysis indicate that the increased exposure to ethanol as a consequence of its use in

**Figure III-1**  Blood ethanol concentration estimates.
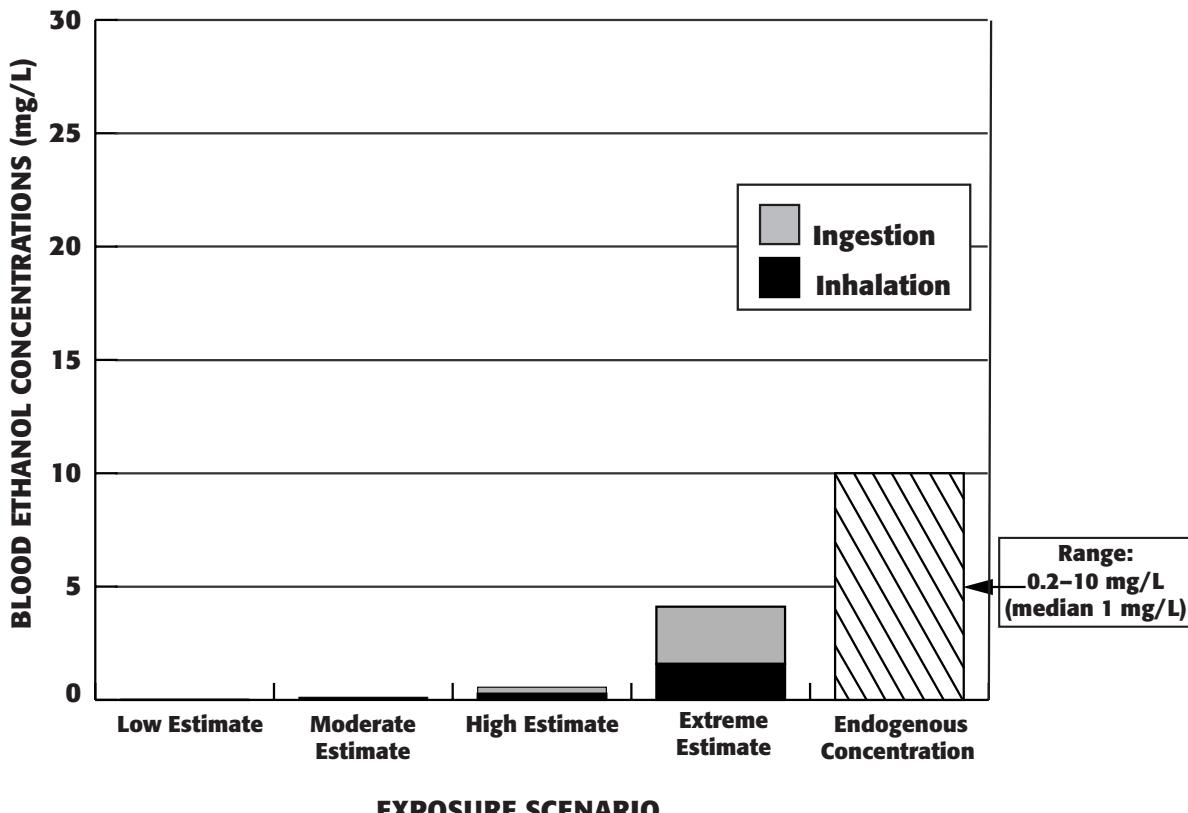
gasoline are not predicted to substantially add to existing endogenous levels of ethanol in the blood (0.2 to10 mg/L). This is because the exposure estimates predicted in this analysis are based on conservative (worst case) assumptions. These assumptions include: volatilization of ethanol equal to that of benzene; drinking water ethanol concentrations at the upper end of the taste threshold; and, most importantly, no metabolic breakdown and excretion of ethanol throughout the 24-hour exposure period. In reality, peak blood levels would be substantially lower than estimated in this analysis because ethanol is metabolized and eliminated from the body relatively quickly (typically in a matter of hours or less) in most individuals.[38] It is also noteworthy that the increase in BECs predicted in the high and extreme scenarios are driven by the degree of ethanol contamination of drinking water.

These findings regarding inhalation risks associated with exposure to ethanol in gasoline are generally consistent with the only other comprehensive risk analyses of exposure to ethanol from its use in gasoline conducted by California's Office of Environmental Health Hazard Assessment (OEHHA) and the 1996 Health Effects Institute Report (see endnote 34). The OEHHA study concluded that likely exposures to ethanol under five modeled fuel scenarios were at least 500-fold lower than concentrations associated with adverse health effects in humans.[39] The HEI 1996 study concluded that it is unlikely that health effects would occur from ethanol inhalation at the very low ambient levels to which people are exposed as a result of adding ethanol to gasoline.

## D. HEALTH EFFECTS ASSOCIATED WITH POTENTIAL CHANGES IN AMBIENT CONCENTRATIONS OF TOXIC AND CRITERIA POLLUTANTS

As discussed in Chapter II, the widespread substitution of ethanol for M*t*BE in reformulated and conventional gasoline blends has the potential to affect pollutant emissions from automobiles both directly and indirectly. These changes raise potential health concerns that must be considered in a comprehensive assessment of health impacts associated with the large-scale introduction of ethanol into Northeast gasoline. Because data are generally lacking to predict the net impacts of ethanol use on ambient air quality in the Northeast, the discussion that follows is largely qualitative. Further modeling is clearly necessary to allow for a more precise assessment; in addition, it will be important to establish monitoring programs to track actual changes in air quality and to better assess the tradeoffs associated with different fuel formulations.

### D.1  Air Toxic Effects

As described in the previous chapter, the potential for an increase in toxic or hazardous air pollutant (HAP) emissions has been identified in connection with the large-scale substitution of M*t*BE by ethanol under the current RFG program. This potential arises primarily from the generation of aldehydes as a by-product of the oxidation of ethanol and ethanol's well-documented effects on fuel volatility—which in turn raise concerns with respect to inadvertent commingling, and impact on vapor recovery systems. There is also a concern that the reformulation of fuel with ethanol may result in increased benzene levels in gasoline because of past overcompliance with the toxics performance standards of Phase I of the RFG program and because of a potential increase in the volatility of benzene in ethanol blends. Overall, this means that toxic emissions could increase relative to current performance even within the toxic emission requirements of Phase II.

#### Monitoring Studies

Any increase in toxic emissions from gasoline would be of concern in the context of recent monitoring data indicating that ambient levels of several HAPs, including benzene, 1,3-butadiene, acetaldehyde, and formaldehyde, already exceed health-protective guidelines in many parts of the Northeast. In the Northeast, mobile sources are estimated to account for well over 60 percent of the total inventory for benzene, 1,3-butadiene, acetaldehyde, and formaldehyde, based on inventory data compiled for the 1996 National Air Toxics Assessment

and assuming regional average 1996 emissions rates. Recent computer modeling of exposure and risks associated with air toxic emissions from all sources in the U.S indicates that on-road motor vehicles are the primary source of these ubiquitous pollutants.[40]

Figure III-2 shows the highest and lowest measured ambient concentrations in the Northeast of several motor vehicle-related HAPs relative to established health-protective guidelines based on cancer effects. The figure indicates that even the lowest measured outdoor concentrations of acetaldehyde, benzene, 1,3-butadiene and formaldehyde—all of which are regulated under the RFG program—already exceed established cancer standards based on one in one million excess cancer risk.[41] The table also shows that the highest measured levels of M*t*BE in the air are about one-half the cancer standard for this pollutant. Unfortunately, there are no comparative data on ethanol concentrations in areas that use ethanol-blended gasoline.

### Modeling Studies

In the 1999 NESCAUM RFG/M*t*BE Study NESCAUM analyzed the Complex Model results with respect to the relative carcinogenic toxicity of specific HAP emissions only. After weighting emissions results according to relative cancer-causing potency, NESCAUM found that the substitution of ethanol for M*t*BE in RFG results in a slight reduction (of approximately 2 percent) in overall carcinogenic risk. If M*t*BE is included in the analysis as a potential carcinogen (and ethanol is not considered a carcinogen), the net effect is to reduce toxic mass emissions by 49 percent and cancer potency-weighted toxicity by 11 percent. NESCAUM's earlier analysis also indicated that toxic emissions associated with conventional gasoline may be expected to decline by about 11 percent (on both a mass and cancer potency weighted

**Figure III-2**   Northeast regional ambient monitoring results compared with health protective thresholds for cancer.
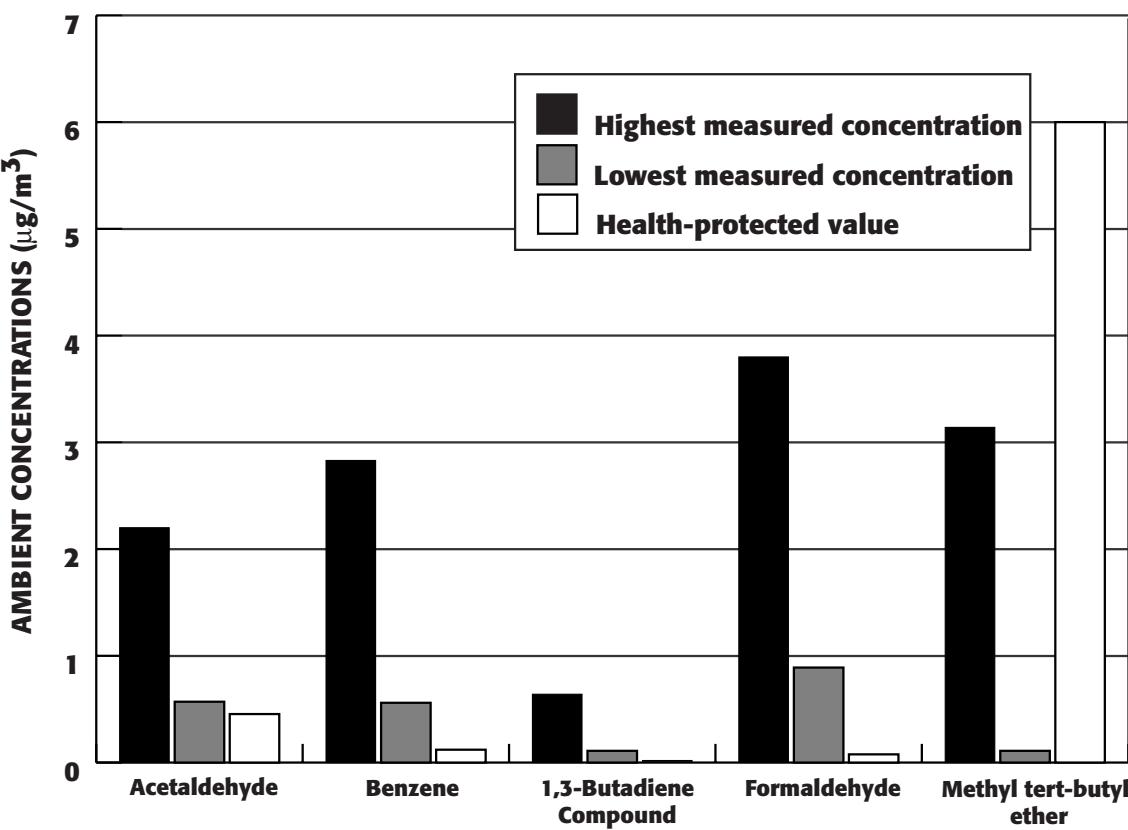
basis) if ethanol replaces M*t*BE in RFG, presumably because the increased use of ethanol in conventional gasoline (for reasons explained in Chapter II) displaces more toxic compounds such as benzene.

The above findings are subject to at least three important caveats:

First, the Complex Model was developed to determine if candidate reformulated gasoline passed or failed the statutory performance requirements. It was not intended to predict individual vehicle emissions or fleet emissions. It also does not take into account high emitting vehicles, which contribute substantially more emissions than the model predicts. Additionally, the Complex Model emissions results are driven by input assumptions concerning the likely formulation of Phase II RFG that may or may not prove accurate depending on future market dynamics for competing fuel constituents.

Second, the results of NESCAUM's earlier analysis of relative toxicity are driven by cancer risks when, in fact, non-cancer health risks may be the more relevant concern associated with ethanol use in gasoline. For example, the exacerbation of asthma from increased exposure to acetaldehyde may be a critically important health concern.[42] There may also be trade-offs in terms of relative emissions of acetaldehyde vs. formaldehyde. Both substances are respiratory irritants that act on the eyes, nose, throat and lungs and both may play a role (though that role is as yet not well understood) in the manifestation of important non-cancer health effects, such as the exacerbation of asthma.[43] Although the intrinsic toxicity of formaldehyde, which is 800 times more irritating than acetaldehyde and has a unit risk value that is six times higher than acetaldehyde, indicates that it is significantly more toxic than acetaldehyde, it is necessary to know how much of an increase in acetaldehyde will occur from the replacement of M*t*BE for ethanol to assess the risks associated with these combustion by-products.

Third, in order to evaluate health impacts associated with potential changes in acetaldehyde, formaldehyde, and other HAP emissions it is necessary to assess changes in pollutant concentrations both in the ambient atmosphere and in relevant microenvironments, such as roadside areas, service stations and parking garages. Exposures that may be most relevant with regard to acetaldehyde and formaldehyde and certain other HAP emissions are the short-duration (< 6 hour) peak exposures that occur in these microenvironments. The potential for such exposures has not been adequately characterized. Another critical concern is the potential increase in evaporative ethanol emissions from permeation of ethanol and other toxic fuel constituents that, in turn, may substantially increase microenvironmental exposure to ethanol and other toxics, such as benzene.

Given existing levels of mobile source toxics in the Northeast, any increase in ambient concentrations owing to one or more of these factors would be of concern. In future region-specific assessments, particular attention will need to be paid to potential impacts on benzene and acetaldehyde and formaldehyde levels both in the ambient atmosphere and in microenvironments that may be associated with acute exposures.

## California analysis and other studies

In terms of ambient air quality impacts, an analysis conducted for southern California indicated that while the use of ethanol-blended RFG would increase that region's inventory of primary acetaldehyde emissions from 6 to 30 percent in aggregate (depending on whether ethanol was blended at 2 percent oxygen by weight or 3.5 percent by weight), the resulting impact on ambient acetaldehyde concentrations would be relatively negligible. Specifically, California's modeling results indicated a change in maximum one-hour acetaldehyde concentrations of only 0.2 to 0.4 ppb relative to a baseline value of 16.7 ppb for M*t*BE-blended California Phase 3 RFG compliant fuel (all these results are for 2003). There was no predicted change in maximum daily acetaldehyde concentrations. Changes in modeled ambient concentrations of formaldehyde were similarly negligible, though slightly more

pronounced than in the case of acetaldehyde. These findings may be explained by the fact that secondary production of acetaldehyde in the atmosphere from other hydrocarbon emissions dominates any effect from changes in direct acetaldehyde emissions. Indeed, California concluded "other components of gasoline, such as aromatics and olefins, are primarily responsible for the formation of acetaldehyde, formaldehyde and PAN (peroxy acetyl nitrate) due to both their greater abundance in gasoline and shorter atmospheric lifetimes."

However, the California results are driven by a number of input assumptions that may or may not be transferable to the Northeast context, especially since they do not address outstanding concerns regarding existing levels of acetaldehyde that exceed health protective levels and the potential acute microenvironmental impacts noted above. Region-specific factors that would need to be considered in performing a similar modeling analysis for the Northeast include the composition of the vehicle fleet, the number of vehicle miles traveled, the contribution of other pollutants from motor vehicles and other sources, the likely composition of both conventional and reformulated gasoline given different supply/demand assumptions for competing fuel constituents, the potential for commingling and other indirect emissions impacts (including relative effects on the volatility of benzene), and local atmospheric conditions.

Evidence on ambient air quality impacts from available monitoring studies is mixed. A study performed in Denver, Colorado—where 10 percent ethanol blends have been increasingly used to reduce ambient carbon monoxide levels—found that concentrations of formaldehyde and acetaldehyde during the winter of 1995/96, when nearly all gasoline was blended with ethanol, were not significantly different from those measured during the winter of 1988/89 when 95 percent of the gasoline was blended with M*t*BE.[44] On the other hand, studies of some locales in Brazil,[45] where ethanol is used in large quantities, and of Albuquerque, New Mexico, where 10 percent ethanol blends are similarly used to reduce wintertime carbon monoxide levels,[46] found evidence for increased acetaldehyde and peroxyacetylnitrate (PAN) concentrations that may be attributable to ethanol use. Although these findings suffer from methodological shortcomings (in the case of Brazil, most automobiles lack comparable pollution control equipment and data on air quality prior to the introduction of ethanol are not available; in the case of the Albuquerque study, Gaffney et al.'s findings have been critiqued by Whitten[47] for failing to establish control conditions or to take into account meteorological variation) the potential health risks associated with atmospheric transformation products are a serious public health concern, and support the need for region-specific assessments of exposure to gasoline constituents and their combustion by-products in the Northeast.

## D.2  Criteria Pollutant Effects

Gasoline-powered vehicles are an important source of reactive volatile organic compounds (VOCs)[48] and NOx, which combine in the atmosphere in the presence of sunlight to form troposhperic (ground-level) ozone. Ozone smog remains a persistent summertime problem in the Northeast where many areas are still in non-attainment of current health-based ambient air quality standards for ozone. As a powerful respiratory irritant, ozone is linked to a number of adverse health effects that effect large segments of the population, especially the elderly, children and individuals with existing respiratory problems. Gasoline-powered motor vehicles account for approximately one-third of the summertime VOC and NOx inventory in the NESCAUM region.

Direct mass emissions of NOx and VOC from RFG would not be expected to change as a result of substituting ethanol for M*t*BE, since these emissions are limited by the performance requirements of the program.[49] Moreover, according to the National Research Council (NRC), use of ethanol is also not expected to affect the overall reactivity (i.e., propensity to form ozone) of specific VOCs emitted under different fuel scenarios.[50] The NRC did find that evaporative emissions from motor vehicles using ethanol-blended RFG could be significantly higher than for M*t*BE-blended RFG if RVP constraints were relaxed. Even if this were not allowed, some potential for increased

evaporative emissions would likely remain with respect to ethanol-blended conventional gasoline, cases of commingling, and other unanticipated impacts that are not covered by current program requirements (e.g., increased permeability through fuel lines, degradation of carbon canisters, etc.). Assuming continued compliance with RFG performance standards, modeling conducted for California found that the replacement of M*t*BE with ethanol in California Phase 3 RFG would have negligible to zero impact on maximum 1-hour and 8-hour ambient ozone concentrations in the South Coast Air Basin.

This result is not surprising, of course, since it is based on an assumption that ethanol-blended RFG meets the same performance requirements as M*t*BE-blended RFG. To what extent these findings account for the several ways, described in Chapter II, that emissions (especially evaporative emissions) could change or increase outside the bounds of current program requirements—and to what extent these findings are therefore transferable to the Northeast context—is unclear. For example, California assumed that commingling would not play an important role because RFG requirements, including the current oxygenate mandate, currently apply to 80 percent of the state's overall fuel market. While the California market share of RFG is not dissimilar to that of the Northeast, where RFG accounts for 75 percent of the region's total market, the potential for commingling may be greater in parts of the region near state borders and/or near rural/urban interfaces.

To the extent that any of the tailpipe, evaporative, or indirect emissions impacts discussed in Chapter II could in fact lead to increased NOx and VOC emissions, they may exacerbate ambient fine particle as well as ozone pollution problems. Fine particle pollution has been linked to a number of adverse human health effects, including excess morbidity and mortality associated with cardiovascular and respiratory effects. Again, further modeling and monitoring studies specific to the Northeast context, and a better understanding of the magnitude of potential emissions impacts, would be necessary to evaluate related health risks.

## HEALTH IMPACTS ASSESSMENT

# E. UNCERTAINTIES AND RECOMMENDATIONS

Despite the conservative nature of the MOE analysis, there are several additional caveats that must be considered.

**First, the effects of large-scale exposure to low levels of ethanol are uncertain**. Preliminary data indicate that the exposures associated with ethanol use in gasoline will not add significantly to endogenous ethanol levels naturally produced in the body. However, additional modeling analysis to estimate ambient exposure to ethanol from its use in Northeast gasoline is needed to confirm these findings. Specifically, MOBILE modeling of ethanol emissions and airshed modeling needs to be conducted in the Northeast, and atmospheric fate of ethanol in a NOx-limited environment needs to be evaluated. In addition, studies are needed to elucidate the dose response for the critical health effects associated with low-level and episodic high level exposures to ethanol.

**Second, more reliable estimates of the potential public health risks associated with short and long-term exposures to ethanol will require a better understanding of the potential teratogenic effects associated with low concentrations of ethanol.** At the present time, *a threshold has not been identified for potential teratogenic effects of ethanol*. Although the exposures predicted in the MOE analysis do not add substantially to endogenous levels of ethanol, the current public health position is to reduce all exposures to ethanol during pregnancy. All exposure scenarios - especially those that may result in short-term high exposures - such as during refueling, as well as chronic low level exposure, need to be considered with respect to the potential for low level prenatal exposure to ethanol.

**HEALTH IMPACTS ASSESSMENT**

# UNCERTAINTIES AND RECOMMENDATIONS continued

**Third, the analysis only considers exposure to ethanol and does not consider exposure to other by-products of ethanol, which may pose a greater hazard than exposure to ethanol itself.** Research is needed to estimate exposure to acetaldehyde, which is produced both as an ethanol metabolite in the body and as an emission by-product from ethanol combustion, and to estimate exposure to increases in other toxic emissions from future fuel reformulation,[51] and exposure to other volatile organics (such as benzene, toluene, xylenes, and ethylbenzene, BTEX) that would be released in a gasoline spill.

**Fourth, exposure estimates are limited by significant data gaps with respect to ethanol concentrations in ambient air or drinking water supplies in areas that use ethanol-blended gasoline.** To date, potential exposures to ethanol in areas that currently use ethanol-blended gasoline have not been adequately evaluated. At a minimum, a comprehensive modeling assessment similar to the one conducted in California is required before ethanol-blended gasoline is introduced on a large scale in the Northeast. The assessment should also include a more refined exposure analysis using personal activity diaries and other data that are more specific to the Northeast context.

**Fifth, a better understanding of the distribution of exposure and attendant health risks, especially among at-risk subpopulations, is needed**. This includes an evaluation of population variability in metabolic processing and in the elimination rates of ethanol, especially in children, an issue that has not been considered in this report. A critical question also centers on understanding the range of potential metabolic variability across populations. For example, it is estimated that 50-80 percent of Asian populations experiences higher than average levels of acetaldehyde from ethanol exposure due to a genetic deficiency in the enzymes that metabolize acetaldehyde. Although it appears unlikely that the "flushing syndrome" that results from this deficiency will be triggered from refueling, an assessment by Froines et al. provides suggestive evidence of the possibility that asthmatics who do not metabolize acetaldehyde well might be potentially at-risk from ethanol exposure.

**Sixth, the possibility that ethanol can interact with medicines or other environmental chemicals, such as benzene, that are metabolized by the same enzyme system were not considered in this analysis.** In particular, patients taking medications for alcoholism (disulfiram) and captopril for cardiac disorders may be at-risk.

**Finally, it should be noted that the potential for higher occupational exposures to ethanol has not been considered in this work.** Potential exposures to workers involved in ethanol and gasoline storage and transfer and—in the event that the region develops its own production capacity—workers at ethanol production facilities, may need to be evaluated. Available monitoring evidence suggests that occupational inhalation exposures could occur at concentrations as high as 60.13 mg/m$^3$, at which point a blood ethanol concentration of 5.9 mg/L would be predicted assuming an 8-hour exposure period (using the methodology described in a previous section).[52]

## CHAPTER III ENDNOTES

[1] Polycyclic Organic Matter (POM) is also a major constituent of gasoline exhaust and listed in Section 202(l) of the Clean Air Act as one of five primary motor vehicle air toxic compounds.

[2] A carcinogen is a substance or process capable of increasing the incidence of neoplasms (tumors) or decreasing the time it takes for a neoplasm to develop.

[3] National Research Council (1999) Ozone Forming Potential of Reformulated Gasoline. Committee on Ozone-Forming Potential of Reformulated Gasoline. National Academy Press. Washington, D.C.

[4] NESCAUM (1999) RFG/MTBE Summary and Findings and NESCAUM (1998) Relative Cancer Risks of Reformulated Gasoline and Conventional Gasoline Sold in the Northeast. (www.nescaum.org)

[5] In May 2000, the New England Governors' Conference (NEGC) requested that NESCAUM and NEIWPCC evaluate the public health impacts of alternatives to MTBE prior to a change in the fuel supply that may result in the addition of new compounds or a substantial increase in existing fuel components. As discussed in previous chapters, the primary alternative to MTBE is ethanol.

[6] Some of these potential emissions impacts were discussed in the previous chapter: they include possible changes in toxic emissions relative to historic overcompliance with RFG program requirements, increases in evaporative emissions generally due to ethanol's volatility impacts, changes in fuel formulations to address volume and octane loss, and emissions associated with the transport of ethanol to the Northeast. This may also include assessment of the indirect emissions associated with the transport and storage of ethanol in the Northeast (and perhaps in the future, its production in region as well).

[7] For example, MOBILE modeling of ethanol emissions and airshed modeling needs to be conducted in the Northeast, as well as atmospheric fate of ethanol in a NOx-limited environment needs to be evaluated.

[8] By adding the exposure to MTBE concentration that occurs in different environments a total exposure dose is determined.

[9] NEIWPCC (2001) Health Effects of Ethanol. In Health, Environmental, and Economic Impacts of Adding Ethanol to Gasoline in the Northeast States. Volume 3: Water Resources and Associated Health Impacts. Chapter 3. July.

[10] The resulting predicted range of exposures is translated into a range of "worst case" blood ethanol concentrations (BECs).

[11] James, John, T. (1997) Ethanol. In Spacecraft Maximum Allowable Concentrations for Selected Airborne Contaminants, Volume 3. The National Academy of Sciences, Washington, DC. www.nap.edu

[12] The Occupational Safety and Health Administration (OSHA), National Institute Of Safety and Health (NIOSH), and American Conference of Governmental and Industrial Health (ACGIH) have established a workplace "no effect level" of 1000 ppm to protect against the irritation effects of ethanol.

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

[14] Reference Concentration (RfC for inhalation) and Reference Dose (RfD for ingestion) are an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation or ingestion 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.

[15] Caldwell, Jane C., Woodruff, T.J., Morello-Frosche, R., Axelrad, D.A. (1998) 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.

[16] US Environmental Protection Agency (1996) Draft Document For the Assessment of Hazards of MTBE. National Science and Technology Council, Washington, DC.

[17] EPA – Environmental Protection Agency, IARC – International Agency for Research on Cancer and NTP – National Toxicology Program

[18] Ethanol is primarily metabolized in vivo through the cytochrome P450 and the alcohol dehydrogenase pathway. Through these enzymatic pathways ethanol is ultimately oxidized by alcohol dehydrogenase to form acetaldehyde and then further modified by aldehyde dehydrogenase to acetate. These metabolic pathways are common detoxification and excretion pathways for a number of compounds. Ellenhorn, M.J., Barcelous, D.G. (1988) Medical Toxicology - Diagnosis and Treatment of Human Poisoning. Elsevier Science Publishing Co., Inc., New York, and Von Wartburg, J.P., Buhler, R. Biology of Disease: Alcoholism and Aldehydism: New Biomedical Concepts. Laboratory Investigation, Vol. 50, Issue 1, pp. 5-15.

[19] Ibid.

[20] Bosron, W.F., Li, T.K. (1986) Genetic polymorphism of human liver alcohol and acetaldehyde dehydrogenases and their relationship to alcohol metabolism and alcoholism. Hepatology, Vol. 6, pp. 502-510.

[21] Froines, J., Collins, M., Fanning, E., McConnell R., Robbins, W., Silver, K, Kun, H., Mutialu R., Okoji, R., Taber, R., Tareen, N., Zandonella, C. (1999) An Evaluation of the Scientific Peer-Reviewed Research and Literature on the Human Health Effects of MTBE, its Metabolites, Combustion Products and Substitute Compounds (located at www.tsrtp.ucdavis.edu/mtberpt.)

[22] Casarett & Doull's Toxicology The Basic Science of Poisons: Companion Handbook. 5th Edition. Casarett, L.J., Klaassen, C.D. Watkins, J. Editors. Macmillan Co., Inc., New York.

[23] To account for the potential increased indoor air concentration of ethanol due to the volatilization of ethanol from showering or heating domestic water for each exposure scenario, it was assumed that 1/100 of the water's ethanol concentration was added to the measured indoor air concentration.

[24] Yasuhara, A. et al., (1981) Environmental Science and Technology, Vol. 15: pp. 570-573. The investigators did not clarify the meaning of "good". It is assumed that it is not directly impacted by ethanol contamination.

[25] The derivation of the NEIWPCC daily comparative value is described in the companion NEIWPCC report. Briefly, it originates from a lowest dose reported with adverse fetal developmental effects (i.e., 0.20 g/kg/day or roughly one drink—12 mg of ethanol—per day for a 60 kg. female). Following common practice in the application of multiple uncertainty or safety factors to derive a health-protective threshold value for human exposure from animal studies, Ginsberg and Chute divide the 0.20 g/kg/day figure by 3000 to account for uncertainties in translating results from a LOAEL to a NOAEL, inter-individual variation in response to ethanol exposure, data gaps in the available dose-response literature, and the potential for cancer risks associated with long-term (chronic) exposure to ethanol. This yields a proposed comparative value of 0.067 mg/kg/day or 4 mg per day for a 60 kg adult.

[26] NEIWPCC assumed a default Relative Source Contribution factor for drinking water of 20%, which ensures that no more than 20% of the total exposure can come from drinking water.

[27] For 6 mg/L: American Society for Testing and Materials (1978) Compilation of Odor and Taste Threshold Values Data. F.A. Fazzalari, Editor. Philadelphia, PA. For 50 mg/L: Keith, E.S. and Powers, J.J. (1968) Journal of Food Science, Vol. 33, pp. 213-218.

[28] Wallace, L. (1996) Environmental Exposure to Benzene: An Update. Environmental Health Perspectives, Vol. 104, Supplement 6.

[29] Andersson, P. and Victorin, K. (1996) Inhalation of Ethanol: Literature Survey and Risk Assessment (IMM-Rapport). Institute for Miljomedicin (Institute of Environmental Medicine), Karolinska Institute, Stockholm, Sweden. March; and Jarke, J.H. (1981) Household Air Concentrations from Chicago, Il. American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. Tran. 87: pp. 153-166.

[30] Personal Communication between Mark K. Allen, Wisconsin DNR and Margaret Round, NESCAUM. December 13, 2000.

[31] By comparison, ambient ethanol concentrations as high as 0.339 to 0.584 mg/m$^3$ have been measured in Sao Paolo Brazil. However, these concentrations reflect substantially higher ethanol use and largely uncontrolled emissions. At the time these concentrations were recorded, some 28 percent of vehicles in Sao Paolo were running on a 22 percent ethanol blend and many of these cars lacked catalytic converters and other pollution control equipment. Grosjean, E., Grosjean, D., Gunawardena, R., and Rasmussen, R.A. (1998) Ambient Concentrations of Ethanol and Methyl tert-Butyl Ether in Porto Alegre, Brazil, March 1996-April 1997. Environmental Science and Technology, Vol. 32: pp. 736-742.

[32] Henry's law constant units are H[-] = H[(atm-m$^3$)/(mole)]/RxT. Where R = 0.08206 [(atm-m$^3$)/(mole-K)] and where T is temperature in degrees Kelvin ( K = degrees Celsius + 273).

[33] Malcolm Pirnie, Inc. (1998) Evaluation of the Fate and Transport of Ethanol in the Environment. Prepared for the American Methanol Institute, Washington, D.C.

[34] Note that the methodology used follows that of Health Effects Institute (1996) Potential Health Effects of Oxygenates Added to Gasoline: A Review of the Current Literature. See also Laboratory Test Handbook (1996) 4$^{th}$ Edition. Jacobs, D.S.; Demott, W.R.; Grady, H.J; Horvat, R.T.; Huestis, D.W.; and Kasten, B.L. Editors. Lexi-Com Corp. Inc.

[35] The absorption factor is from James, John, T. (1997) Ethanol. In Spacecraft Maximum Allowable Concentrations for Selected Airborne Contaminants, Volume 3. The National Academy of Sciences, Washington, DC. (www.nap.edu)

[36] Note that the inhalation concentrations assumed for indoor and outdoor air and during refueling are the same in the moderate-high and extreme cases. The only difference between the two high-end scenarios is in the level of ethanol contamination assumed for household water supplies (which leads to higher exposures from ingestion and inhalation while showering or bathing and slightly higher (i.e., 1/100$^{th}$ of shower/bath concentration) indoor air concentrations.

[37] Medicolegal Aspects of Alcohol (1996) Garriott, J.C. Editor. Lawyers and Judges Publishing Company, Inc. Tucson, AZ. Endogenous blood concentration of 0.2 mg/L to 27 mg/L are cited in the HEI, 1996. The 10 mg/L is used as an upper bound in the companion NEIWPCC report. Other data indicate that the range is 0.2 to 2 mg/L, with a median of 1 mg/L.

[38] It is estimated that metabolic breakdown and elimination typically account for a 5-fold reduction in blood ethanol levels over a 6-hour exposure period. Pastino, G.M., Asgharian, B., Roberts, K. Medinsky, M.A. (1997) A Comparison of Physiologically Based Pharmacokinetic Model Predictions and Experimental Data for Inhaled Ethanol in Male and Female HB6C3F Mice, F344 Rats, and Humans. Toxicology and Applied Pharmacology, Vol. 145, pp. 147-157.

[39] California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (OEHHA). 2000. Potential Health Effects on Ethanol in Gasoline. (www.oehha.ca.gov/air/etoh/ETOHfin2.html#download)

[40] Specifically, mobile sources accounted for 70.6% of the benzene inventory; 65.4% of the 1,3 butadiene inventory; 61.6% of the acetaldehyde inventory; and 68% of the formaldehyde inventory. (Note that secondary formation accounted for another 9.4% of the 1,3-butadiene inventory.) See NESCAUM Inventory Assessment and Comments on the 1996 National Toxics Inventory submitted to USEPA, July 1999. (www.nescaum.org).

[41] For cancer risks, the benchmarks shown here denote the concentration of a known, probable, or possible human carcinogen that could theoretically result in one excess cancer per million exposed individuals assuming lifetime (chronic) exposure. The benchmarks shown in this figure are meant to serve as general indicators of potential concentrations of concern. It is important to recognize that these values cannot necessarily be used to predict the likelihood of a particular cancer based on ambient concentrations and that they do not consider exposure thresholds associated with potential non-cancer effects.

[42] Marnett, Lawrence J. (1988) Health Effects of Aldehydes and Alcohols in Mobile Source Emissions in Air Pollution, the Automobile, and Public Health. Watson, A.Y., Bates, R.R., Kennedy, D. Editors. National Academy Press, Washington, DC.

[43] In addition to non-cancer effects, chronic exposure to acetaldehyde has been shown to cause nasal and laryngeal tumors in rat and hamster studies, but the data are limited and considered inadequate to assess carcinogenicity in humans. Formaldehyde has been classified by EPA as a Group B-1 probable carcinogen.

[44] Anderson L.G., J.A. Lanning, E. Wilkes, P. Wolfe, and R.H. Jones (1997) Effects of Using Oxygenated Fuels on Carbon Monoxide, Formaldehyde and Acetaldehyde Concentrations in Denver. Paper 97-RP139.05, Air & Waste Management Association 90th Annual Meeting & Exhibition, June 8-13, 1997, Toronto, Ontario, Canada.

[45] Grosjean E., D. Grosjean, R. Gunawardena, and R.A. Rasmussen (1998) Ambient Concentrations of Ethanol and Methyl tert-Butyl Ether in Porto Alegre, Brazil, March 1996-April 1997. Environ Sci Tech, 32, pp. 736-742; and de Andrade J.B., M.V. Andrade, and H.L.C. Pinheiro (1998) Atmospheric Levels of Formaldehyde and Acetaldehyde and their Relationship with the Vehicular Fleet Composition in Salvador, Bahia, Brazil. Journal of Brazilian Chemical Society, Vol. 3, pp. 219-223; and Tanner R.L., A.H. Miguel. J.B. de Andrade, J.S. Gaffney, and G.E. Streit (1998) Atmospheric Chemistry of Aldehydes: Enhanced Peroxyacetyl Nitrate Formation from Ethanol-Fueled Vehicular Emissions. Environ Sci Tech 22, 1026-1034.

[46] Gaffney J.S., N.A. Marley, R.S. Martin, R.W. Dixon, L.G. Reyes, and C.J. Popp (1997) Potential Air Quality Effects of Using Ethanol-Gasoline Fuel Blends: A Field Study in Albuquerque, New Mexico. Environ Sci Tech, 31, 3053-3061; and Gaffney J.S., N.A. Marley, R.S. Martin, R.W. Dixon, L.G. Reyes, and C.J. Popp (1998) Response to Comment on Potential Air Quality Effects of Using Ethanol-Gasoline Fuel Blends: A Field Study in Albuquerque, New Mexico. Environ Sci Tech, 31, 3053-3061.

[47] Whitten G.Z. (1998) Comment on 'Potential Air Quality Effects of Using Ethanol-Gasoline Fuel Blends: A Field Study in Albuquerque, New Mexico. Environ Sci Tech, 32, 3840-3841.

[48] Note that VOCs constitute a broad category of volatile hydrocarbons that includes many of the toxic air pollutants discussed above (e.g., benzene, acetaldehyde and formaldehyde).

[49] As discussed in Chapter II, the Complex Model would not predict emissions increases, but there may still be some potential for changes in tailpipe emissions in actual on-road driving.

[50] National Research Council (1999) Ozone-Forming Potential of Reformulated Gasoline. Committee on Ozone-Forming Potential of Reformulated Gasoline. National Academy Press, Washington, DC

[51] The increases may be due to significant changes in RFG composition due to losses in volume and octane from substituting ethanol for MTBE, increases in toxic emissions while still complying with Phase II RFG requirements, increases in evaporative emissions (from older vehicles, commingling, fuel permeation, and possible increases volatility of benzene), and increases in combustion by-products, most notably acetaldehyde.

[52] High occupational exposures reported by Vershueren, K. (1983) Handbook of Environmental Data or Organic Chemicals. 2nd edition, Van Nostrand Reinhold Co., New York.
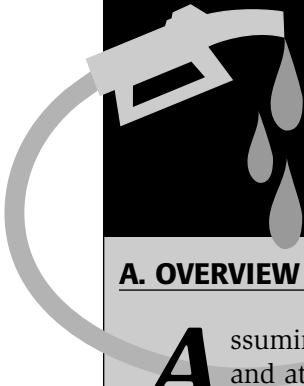
# CHAPTER IV

# ECONOMIC IMPACTS OF REPLACING M*t*BE WITH ETHANOL

## A. OVERVIEW

*A*ssuming that ethanol would be blended in future RFG at 5.7 percent by volume and at as much as 10 percent by volume in conventional gasoline,[1] total annual ethanol demand in the Northeast could be as high as 900 million gallons at current rates of gasoline consumption. It should be emphasized that this figure represents a maximum estimate. Actual ethanol demand in the Northeast is likely to be less, particularly if ethanol supplies are constrained as a result of new restrictions on M*t*BE use elsewhere in the nation. Nevertheless, the region's demand for ethanol can be expected to increase substantially, even if only the minimum necessary to meet the oxygen mandate is used. Specifically, at 5.7 percent volume in RFG only, the region's total demand for ethanol would still reach 670 million gallons annually, based on current consumption. Of course, most energy forecasts assume that gasoline demand will continue to grow concurrent with continued growth in vehicle travel. According to the most recent federal projections, gasoline demand in the NESCAUM region can be expected to grow by approximately 7 percent between 1999 and 2003. This would translate to a potential regional annual ethanol demand of 720 to 960 million gallons by 2003.

The large-scale replacement of M*t*BE by ethanol would, according to most analyses, increase the cost of gasoline. The magnitude of these cost increases will be driven by four primary factors:

- ▲ The cost/availability of ethanol

- ▲ The cost/availability of low-RVP blendstocks

- ▲ The time allowed to transition from M*t*BE to ethanol

- ▲ The cost of new or modified infrastructure for transporting, storing, and blending ethanol; and the implementation of needed refinery modifications

The first three of these cost components are discussed in the next section, which summarizes available data on the magnitude of likely, overall costs associated with the reformulation of gasoline (both conventional and RFG) using ethanol instead of M*t*BE to satisfy the current oxygenate and octane requirements. It must be emphasized that all the estimates of economic impact cited in this report are taken from outside sources. NESCAUM itself did not conduct any new analyses. Because of the large numbers of variables involved, it is perhaps not surprising that different analysts come to different conclusions about the range of possible cost impacts associated with a broad-scale shift to ethanol. Specific economic costs and issues related to the need for a new ethanol infrastructure, and the potential costs and benefits of developing an indigenous ethanol production base within the Northeast using alternative biomass feedstocks (instead of corn) are discussed in subsequent sections.

## B. COST OF FUEL REFORMULATION

As discussed in Chapter II, the use of ethanol in place of M*t*BE to meet the oxygenate requirements of the federal RFG program would likely necessitate other changes to the formulation of both RFG and conventional gasoline for at least two important reasons: to compensate for the volatility effects of adding ethanol and to compensate for the volume and octane lost when M*t*BE (which currently comprises as much as 11 percent of RFG) is replaced by a smaller volume (5.7 percent) of ethanol. Compensating for lost volume and octane may present a significant challenge and one with substantial cost implications—at least in the early years of a transition away from M*t*BE. Addressing these issues in the formulation of RFG might well result in changes to the formulation of conventional gasoline. It will almost certainly drive up demand for other low-toxicity octane boosters such as alkylates.

Changes in fuel formulation are likely to increase costs in at least two ways: (1) process changes and equipment modifications will be needed at the refinery and (2) M*t*BE alternatives such as alkylate and ethanol are likely to be more expensive. The magnitude of these costs is highly sensitive to a number of interdependent variables and is therefore difficult to forecast. Important factors include the timeframe over which fuel changes are phased in, the relative supply and demand for various fuel constituents (which is in turn dependent on whether other areas of the country, such as California, institute similar fuel changes), and the longer-term prospects for developing ethanol production capacity nearer to the areas where RFG use is concentrated, such as along the East and West coasts. Federal policy changes could clearly have a major impact: the cost implications of lifting the current oxygenate mandate and replacing it with an annually averaged renewable fuels requirement could, for example, be much different from the cost implications of maintaining the current mandate while phasing out M*t*BE.

Given the complexity of forecasting fuel price changes, relatively few analyses of the likely cost impacts of a large-scale shift from M*t*BE to ethanol are available. Perhaps most relevant to northeastern policy makers are studies sponsored by the U.S. Department of Energy (USDOE) and the California Energy Commission (CEC). In 1999, USDOE looked specifically at cost implications for East Coast (PADD I) refineries.[2] It estimated that the average cost of RFG produced at PADD I refineries would increase by 3.9 cents per gallon if all M*t*BE were replaced by 2004 under a nationwide ban on ethers (including M*t*BE) and a continuation of the existing oxygenate mandate.[3] Under this scenario, USDOE estimated that ethanol demand at PADD I refineries would increase to over 400 million gallons per year, with concurrent substantial increases in the demand for alkylates and reformate. In addition to the added cost of ethanol, USDOE's estimated cost increase includes a slightly greater input of crude oils and a small expansion of crude and vacuum distillation capacity, as well as additional reformer capacity and associated naphtha hydrotreating capacity. Importantly, the USDOE analysis was premised on the assumption that refineries will meet only the minimum regulatory requirements for toxic air emissions (which would have the effect of increasing actual emissions by 35 percent relative to current levels) and that they will be allowed to produce both ethanol and non-ethanol gasoline blends.

More recent analyses conducted by USDOE's Energy Information Administration (EIA) in 2000 produced higher estimates of the incremental costs of banning or limiting M*t*BE use. Specifically, EIA used the Petroleum Market Module (PMM) of its National Energy Modeling System (NEMS) to evaluate the following four scenarios:

1. M*t*BE content limited to 3 percent effective 2003

2. M*t*BE banned (i.e., limited to 0 percent) effective 2003

3. M*t*BE content limited to 3 percent effective 2003 <u>and</u> 2 percent national renewable fuels standard imposed in 2005; and

4. M*t*BE banned effective 2003 <u>and</u> 2 percent national renewable fuels standard imposed in 2005.

Importantly, all the scenarios initially modeled by EIA assumed that the oxygen requirement would be lifted and that the toxics reduction performance of the current program would be maintained. Using these assumptions, EIA estimated that the incremental cost to produce fuel in 2005 would range from 2 cents per gallon if M*t*BE content were limited to 3 percent and there were no renewable fuels standard in place, to between 5 and 6 cents per gallon if a ban on M*t*BE in 2003 were combined with a 2 percent renewable fuels requirement. Interestingly, EIA's analysis suggests that the imposition of a 2 percent renewable fuels standard would increase national demand for ethanol by only about 14 percent relative to a scenario in which M*t*BE is banned but there is no such standard (from 200,000 barrels per day for scenario (2) compared to approximately 175,000 barrels per day for scenario (4)).

In July 2000, EIA reported on the cost results for an additional scenario in which states ban M*t*BE use in 2003 and the oxygen mandate is maintained (there is no renewable fuels standard in this scenario). Not surprisingly, estimated costs for this scenario are substantially higher—peaking at slightly more than 8 cents per gallon in 2003 and declining to just over 7 cents per gallon in 2005. Figure IV-1 below shows EIA's cost estimates for all five scenarios analyzed. Recognizing that gasoline costs are likely to rise under all scenarios in which M*t*BE use is limited or banned, the results suggest that the incremental cost of maintaining the oxygen mandate is between 4 and 5 cents per gallon relative to eliminating M*t*BE and lifting the mandate. Importantly, the EIA estimates represent a national average and may therefore understate regional costs, which are likely to vary (perhaps significantly) depending on regional supply constraints, blendstock requirements and other factors. Moreover, the EIA estimates were developed using annual average fuel requirements and may therefore minimize the seasonal cost impacts of using ethanol in RFG during the summertime, when RVP is an issue. In addition, EIA did not attempt to account for any additional infrastructure costs that might be associated with expanded ethanol use or for the implementation of new restrictions on the sulfur content of gasoline in the same timeframe. EIA notes that the simultaneous implementation of refinery modifications to address low-sulfur



**Figure IV-1**   EIA estimates of changes in US average gasoline price for different M*t*BE reduction scenarios.[4]
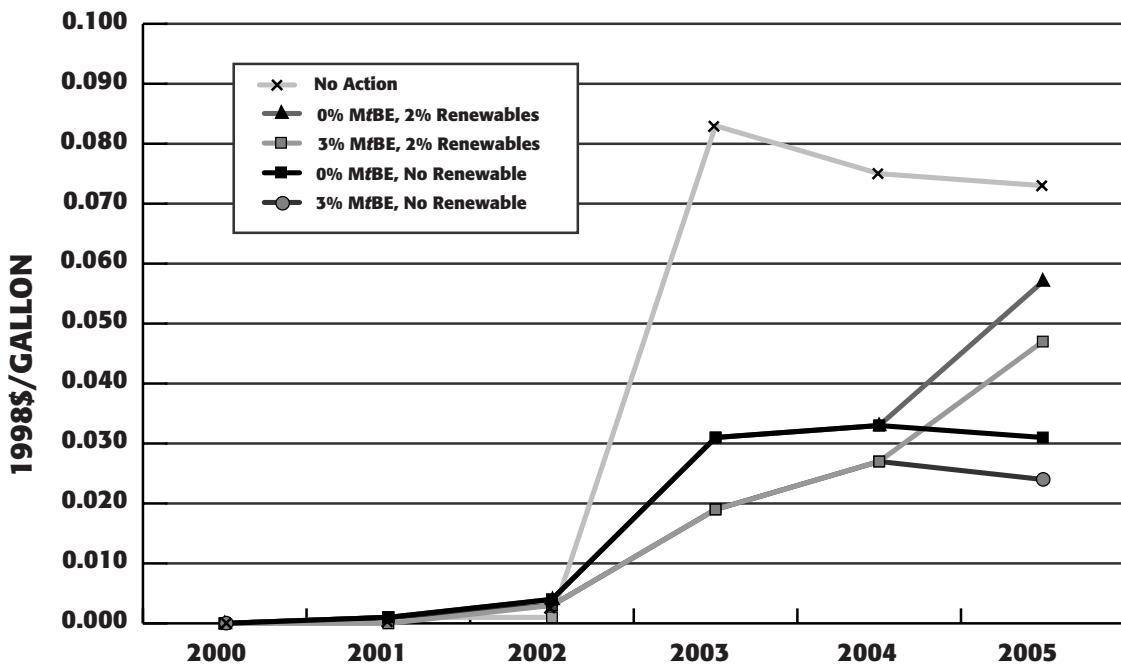
requirements could help to offset the additional costs of modifications needed to switch from MtBE to ethanol. On the other hand, however, EIA also notes that fuel changes needed to meet low sulfur requirements could result in further octane and volume losses, thereby exacerbating the difficulties associated with phasing out MtBE.

A major CEC analysis, also completed in 1999, assumed a ban on MtBE in California with continued oxygenate requirements under the California RFG program. It included detailed estimates of the added costs of using ethanol, including the costs of modifying or adding infrastructure at refineries and distribution terminals, as well as the costs of transporting ethanol from the Midwest and other areas. As part of its analysis, the CEC developed a series of supply curves using different assumptions about ethanol demand and the continued availability of federal tax subsidies. Overall, the CEC estimated that with a three-year lead-time (i.e., MtBE phase-out by 2002), ethanol demand in California alone would increase to 1.15 billion gallons per year (75,000 barrels per day), with demand for additional gasoline imports increasing by 2.18 billion gallons per year (142,000 barrels per day).[5] The incremental price increase for this scenario was estimated to range from 6.1 to 6.7 cents per gallon, with total costs ranging from $902-991 million per year.

The CEC also looked at implementing an MtBE ban over a longer, six-year timeframe (i.e., by 2005). This scenario produced lower long-term incremental costs ranging from 1.9 to 2.5 cents per gallon, with total costs ranging from $298-392 million per year. California ethanol demand in 2005 was estimated at 1.21 billion gallons per year (79,000 barrels per day) under this scenario, with demand for additional gasoline imports rising to 1.73 billion gallons per year (113,000 barrels per day). It is important to note, however, that these estimates assume a phase-out of MtBE in California alone. An initial estimate by the CEC of the implications of a nationwide phase-out of MtBE indicated that intermediate term (3 year) costs to California could rise to 11.7 cents per gallon, while incremental long-term (6 year) costs could rise to 3.7 cents per gallon. Note that the latter figure is similar to USDOE's incremental cost estimate of 3.9 cents per gallon for PADD I refineries assuming a 2004 (rather than 2005) phase-out of MtBE.

The largest component of incremental cost estimated by CEC under various scenarios for replacing MtBE with ethanol comes from so-called variable costs, which include refinery operating costs and the costs of various blendstocks and additives. These costs account for over 70 percent of total incremental cost in the intermediate term scenarios and for 50 percent of total incremental cost in the long-term scenarios. Presumably variable costs account for an even larger share of total incremental cost when the impacts of a nationwide MtBE ban are taken into account, as the chief difference between this scenario and others modeled by California is that it assumes higher overall demand—and hence higher prices—for ethanol and other additives. Other components of incremental cost in the CEC analysis include the need for additional blendstock tankage and inventory (at an estimated cost of 0.1 cents per gallon) as well as the added terminal and transportation costs associated with ethanol blending (at an estimated annualized cost of another 0.1 cents per gallon). Finally, the CEC estimates account for the modest mileage loss associated with ethanol's somewhat lower energy content relative to MtBE. This factor adds from 0.6 to 1 cent per gallon to the incremental cost to consumers of California gasoline formulated with ethanol, depending on the scenario modeled.[6]

Over the next few years, total gasoline consumption in the Northeast is likely to exceed 15 billion gallons annually. Hence, incremental costs on the order of 5 cents per gallon could translate into added regional costs of $750 million annually. Economic impacts could, of course, be substantially higher if incremental costs approach the maximum estimated by California under a shorter transition timeframe or if some of the factors not taken into account by existing analyses prove significant.[7] As noted previously, actual cost impacts are likely to be highly sensitive to the supply and availability of ethanol and to the supply and availability of low-RVP blendstocks. For example, from the figures cited earlier, demand for ethanol in Northeast gasoline could be expected to range from 670 million gallons[8] to a maximum of 960 million gallons by mid-decade. With California adding demand for another 1.2 billion gallons, total <u>new</u> ethanol demand from these two regions

alone could approach 2 billion gallons per year (or 130,000 barrels per day).[9] By comparison, current ethanol production capacity in the U.S. and Canada is on the order of 1.7 billion to 1.8 billion gallons per year.[10] Unless fuel ethanol were shifted out of other markets where it is currently being used,[11] this would imply that existing ethanol production capacity would need to be approximately doubled to meet the additional demand.

A related issue, with respect to the future market price of ethanol, is the issue of market power among ethanol suppliers. In its analysis, the CEC noted that the top 5 U.S. producers control nearly 65 percent of production capacity; one company alone controls nearly half of existing U.S. production capacity. The CEC goes on to note that with "the concentration of ethanol production in the hands of relatively few suppliers, consumers may further be harmed by the lack of competitive market forces." [12] Finally, it is worth noting 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 53 cents per gallon. If these subsidies were to be reduced to offset the budgetary impacts of a major expansion of ethanol use, the price faced by refiners would likely increase, as would prices for ethanol-blended gasoline at the pump.

Similarly, blending ethanol-containing RFG to meet existing RVP limits can be expected to present substantial cost and supply hurdles for refiners. It has been estimated that to meet these limits, a base gasoline with an RVP as low as 5.5 to 5.7 psi may be needed. Many refiners assert that the costs of producing such a blendstock would be prohibitive in the near term and would exacerbate the fuel supply and price volatility problems that were experienced in the summer of 2000. For example, even Midwest refiners serving the Chicago area[13] have indicated that they will need to switch from ethanol to M*t*BE in the summer months because the additional VOC reduction requirements of the Phase II RFG program effectively preclude the use of ethanol. During the summer of 2000, a base RVP of 5.8 psi was required in the Chicago market to comply with Phase II VOC emissions limits. Indeed, some analysts have suggested that blendstock changes necessitated by formulating ethanol blends to meet summertime RVP limits could significantly exacerbate the volume shortfall caused by phasing out M*t*BE. This would be the case, for example, if refiners were forced to remove other volatile (and generally less expensive) gasoline constituents, such as pentanes and butanes, to compensate for ethanol's volatility impacts. The CEC, for example, has recently warned that California's plans to phase out M*t*BE could result in overall gasoline production shortfalls of 6 to 10 percent in 2003.[14] Important factors contributing to this shortfall are likely to be the supply and cost, not only of ethanol, but of alkylates as well. According to the CEC, alkylate supplies are substantially constrained in the near term and alkylate prices have recently increased dramatically.

## C. COST AND REGULATORY IMPACTS OF DEVELOPING AN ETHANOL INFRASTRUCTURE

The cost impact analyses discussed in the previous section generally attempt to capture some or, in the case of the CEC analysis, all of the costs of developing an ethanol infrastructure. This section provides further detail on the specific infrastructure implications of a large-scale shift to ethanol in the Northeast. These implications include both economic costs and regulatory burdens for state and federal authorities that will need to permit infrastructure additions and modifications. The need for new infrastructure derives from the fact that ethanol's unique properties—notably its affinity for water—necessitate different handling and transport methods than have been used for M*t*BE.

As noted previously, roughly 40 percent of the gasoline consumed in the Northeast is refined at East Coast (PADD I) refineries. Almost all of the refinery capacity in PADD I is located in New Jersey and Pennsylvania, with some additional capacity in Delaware. Another 20 percent of the region's gasoline is imported from overseas and delivered by ship to ports along the Atlantic coast. The remaining 40 percent is transported, primarily via pipeline, from Gulf Coast (PADD III) refineries. Gasoline is generally delivered from the refinery to a distribution terminal, which

usually consist of several storage tanks and equipment used to load tanker trucks. From the distribution terminal, gasoline is then transported to service stations by tanker truck.

Generally, M*t*BE is blended with gasoline at the refinery and does not necessitate any special handling throughout the distribution system. Ethanol, by contrast, has an affinity for water. As a result, ethanol-containing gasoline would tend to pick up the small amounts of water that can accumulate over time in pipelines and storage tanks from condensation or minor contamination, thereby degrading overall fuel quality. To avoid this problem, ethanol would need to be transported and stored separately from gasoline until the point where it is loaded into tanker trucks for delivery to service stations. This means that segregated tanks for storing ethanol would be needed at distribution terminals, as well as special blending equipment that would allow ethanol to be loaded onto tanker trucks simultaneously or in sequence with gasoline. Besides incurring additional costs, these infrastructure needs may present other challenges, including siting and regulatory issues. For example, space constraints may prove to be an important issue in siting new storage tanks at existing petroleum refinery and distribution facilities.

The CEC analysis concluded that it would cost as much as $60 million and take from 18 to 24 months to complete necessary modifications to storage tanks, unloading facilities and blending equipment in California. Of these modifications, the most expensive were expected to involve the installation of blending equipment at distribution terminals—which the CEC estimated could cost close to $25 million, involve modifications to nearly 150 truck loading lanes and require up to two years to complete. Modifying existing storage tanks to hold ethanol and building new tanks was estimated to cost an additional $16 million, while the modifications needed to receive ethanol at distribution terminals—including upgrading and expanding rail facilities and truck unloading facilities—would cost an additional $19 million. Assuming that 2004-2005 ethanol demand in the Northeast would be at least 50 percent that of California's (according to the figures cited at the outset of this section) and that necessary capital investments in the distribution infrastructure can be scaled accordingly, suggests that costs in the Northeast would be on the order of $30 million. These additional distribution infrastructure capital costs would tend to raise the price of gasoline by 0.1 cents per gallon at the pump, again assuming that costs per gallon of ethanol throughput in the East are similar to those projected for California. In fact, there are likely to be important differences. For example, in the Northeast, nearly every terminal location is accessible by water, whereas only a few can be accessed by rail. Thus, as much as 60 percent of the ethanol used in the Northeast could be delivered to distribution terminals via ship and ocean-going barge transport, necessitating different modifications than the rail facility changes assumed for California.

Indeed, the likely costs and infrastructure implications of transporting ethanol from production centers in the Midwest to East Coast distribution terminals remains a major area of uncertainty. Pipelines are generally the most economical option for transport over longer distances; for example, the long haul, large diameter pipelines that connect the Gulf Coast to the Northeast can transport petroleum products from Houston to New York harbor at an average cost of $1 per barrel or 2.5 cents per gallon.[15] However, transport of ethanol through such pipelines, according to industry representatives, would likely be "problematic." Proponents of expanded ethanol use have asserted that ethanol could be transported directly from the Midwest using smaller diameter regional pipelines. However, the cost of transport over such pipelines is likely to be more expensive, with tariffs from Chicago to New York reaching as much as 8 to 10 cents per gallon. To the extent that new, dedicated pipelines would need to be built to move ethanol, additional cost and lead-time could be substantial. The construction of new pipelines has become increasingly difficult in terms of obtaining needed permits and rights of way. Industry representatives estimate that the costs of constructing new pipeline are on the order of $1 million per mile. At this cost and assuming 40,000 barrels per day of throughput, the cost charged to transport ethanol through new dedicated pipeline could be on the order of 20 cents per gallon, more or less. Alternatively, it may be possible to transport ethanol in batches through existing pipelines that are also used to carry other products.[16] However, it is unclear how much capacity is available for this purpose, especially

since most current product movement between the East Coast and Midwest is from East to West, rather than the reverse.

In short, pipeline transport of ethanol between the Midwest and East Coast is likely to remain substantially constrained in the near term, though some stakeholders assert that it will be a more viable option in the longer term. The near term alternatives—moving ethanol by rail, tanker truck, or barge—present different cost and environmental implications. For example, it would require 200 tanker trucks per day (at a carrying capacity of 200 barrels per truck) to deliver the same quantity of ethanol as a 40,000 barrel per day pipeline. Transporting 670 million gallons of ethanol per year (or 15.9 million barrels) would require 80,000 tanker truck trips per year. The corresponding figures assuming rail transport (and rail car capacity of 714 barrels) are 22,000 rail car trips per year or 61 rail car trips per day. Of course, as already noted, barge transport is likely to be the primary means for delivering ethanol (as much as 60 percent of total demand) to northeastern distribution terminals in the near term. Given that a single large barge can transport as many as 100,000 barrels, as many as 159 barge trips would be involved in moving 15.9 million barrels of ethanol per year. As with truck and rail transport, this mode of ethanol transport would generate additional air pollutant emissions.

The costs associated with moving large quantities of ethanol between the Midwest and East Coast using barge, tanker truck, and rail have not been separately estimated in the existing USDOE analysis. The CEC analysis assumes that transport costs from the Midwest to California (primarily by rail) will add about 15 cents per gallon to the cost of ethanol. The distances involved in the California analysis are presumably comparable (and perhaps somewhat greater than) those involved in delivering product from the Midwest to the Northeast. However, the preferred modes of transport may be different, with California potentially in a better position to make use of rail transport than the East Coast.

Besides necessitating new investment, infrastructure changes associated with the large-scale use of fuel ethanol in the Northeast will impose new regulatory burdens on the fuel industry and on state and federal regulatory authorities. This is because substantial modifications of existing infrastructure (such as the siting of new ethanol storage tanks at distribution terminals or the expansion of truck or barge off-loading capacity) are likely to require state and, in some cases, local permits. In addition, some types of infrastructure, such as interstate pipelines, are subject to federal regulatory authority. In obtaining regulatory clearance for infrastructure modifications or enhancements, industry may be required to take steps to address environmental impacts, safety issues, and other permit conditions; in turn creating additional review and enforcement obligations for relevant regulatory authorities.

## CHAPTER IV ENDNOTES

[1] Refer to Chapter II on reformulating RFG without M*t*BE.

[2] PADD I refineries account for approximately 40 percent of the gasoline supplied to the NESCAUM states; another 40 percent comes from Gulf Coast (PADD III) refineries and another 20 percent is imported from overseas.

[3] Hadder, G.R. (1999) Estimating Refining Impacts of Revised Oxygenate Requirements for Gasoline: Follow-Up Findings. Oak Ridge National Laboratory. Draft of May 10, 1999. Note that an earlier analysis by Hadder had produced a lower incremental cost figure for RFG of 2.5 cents per gallon. However, this earlier figure understated costs in two ways: first, by not considering likely ethanol price increases in response to supply constraints and second, by modeling regular and premium grades of RFG and conventional gasoline as one pool, rather than separating them. The higher figure of 3.9 cents per gallon is largely driven by an assumption that the price of ethanol would be at least 33 cents per gallon higher than current prices under the modeled scenario.

[4] Summary of "No Action" Scenario Requested by the Senate Committee on the Environment and Public Works," Energy Information Agency, US Department of Energy, July 14, 2000.

[5] California projects that its overall gasoline demand in 2002 will reach 14.8 billion gallons per year; hence this scenario assumes that ethanol would account for 7.8 percent (by volume) of California gasoline under an MTBE ban.

[6] Because of its lower energy content, blending ethanol in gasoline has been estimated to result in a 2 to 3% loss of overall gasoline energy content. However, fuel economy tests on actual vehicles to date have been inconclusive, with some tests showing a mileage penalty, others showing no change, and still others showing slight improvement in fuel economy. This suggests that actual fuel economy impacts may be highly vehicle specific. See Knapp, KT; Stump, FD; Tejada, SB (1998) The Effect of Ethanol Fuel on the Emissions of Vehicles over a Wide Range of Temperatures. Journal of the Air and Waste Management Association, Vol. 48, July 6. and Newkirk, M. S. (1997) Emissions Characterization of Baseline Gasoline and Gasoline/Oxygenate Blends Under Tier 1 of the CAA 211(B) Fuels and Fuel Additives Registration Regulations. American Petroleum Institute, Washington, DC.

[7] Organizations commenting on drafts of this report have cited additional economic analyses, including studies conducted by Turner Mason & Company in 1998 and 1999 and by Pace Consultants in 2000. Because NESCAUM did not have time to independently review these additional analyses, some of which were commissioned by organizations with a particular stake in the current debate, we confine the discussion above to the results of the DOE, EIA, and CEC analyses.

[8] Note that the figure of 670 million gallons of ethanol needed to meet minimum oxygen requirements for all Northeast RFG is higher than the 400 million gallon figure estimated by the DOE ORNL study cited previously for PADD I refineries. This is presumably because some of the gasoline used to supply the Northeast market comes from PADD III refineries.

[9] This result is roughly consistent with EIA's estimate that a ban on MTBE, with no lifting of the oxygen mandate, would increase national ethanol demand to 229,000 barrels per day in 2005, compared to a reference case of 125,000 barrels per day. Absent the oxygen mandate, EIA estimates that national ethanol demand would reach 175,000 barrels per day in 2005 if MTBE is banned.

[10] The 1999 Blue Ribbon Report cites a production capacity figure of 1.8 billion gallons annually; it also cites an EPA figure placing future national demand for ethanol (to meet the requirements of both the RFG and oxyfuels programs) at 2.9 billion gallons per year under a nation-wide MTBE ban.

[11] This would in turn imply that refiners supplying California and the Northeast were willing to pay higher prices for ethanol than those being charged in current markets.

[12] Note that while some ethanol production capacity exists outside the U.S., notably in Brazil, relatively little of this capacity is currently available for export.

[13] Currently, ethanol is used as an oxygenate predominantly in the Chicago metropolitan area, due to its proximity to the ethanol grain feed stocks and production facilities.

[14] Gordon Shremp, CEC Analyst. "California Issues – Expanded Use of Ethanol and Alkylates" Presentation to the LLNL Workshop, Oakland CA, April 10-11, 2001.

[15] According to the Association of Oil Pipelines website (www.aopl.org).

[16] For example, representatives at Williams Pipe Line have indicated that ethanol can be transported in an existing pipeline with other products as long as the interfaces are properly managed. For example, a batch of fuel ethanol could be shipped between a batch of premium unleaded gasoline and unleaded gasoline. The interface containing some unleaded gasoline and ethanol could be 1) reprocessed or 2) blended off. Williams Pipe Line asserts that managing the unleaded/ethanol interface is no more difficult than handling an unleaded/diesel interface.

# CHAPTER V

# COSTS AND BENEFITS OF REGIONALLY PRODUCED ETHANOL[1]

## A. OVERVIEW

*G*iven the dramatic increase in ethanol demand that could occur under a phase-out of M*t*BE (especially under a continued RFG oxygenate mandate) and the supply constraints noted previously, lowering the long-term cost of ethanol to Northeast consumers may depend to a significant extent on the successful development of in-region ethanol production capacity using waste biomass[2] or dedicated biomass feedstocks. This would not only help to overcome the supply, transportation and distribution hurdles noted in the previous chapter, it could boost the region's economy, keeping dollars in the Northeast that would otherwise flow to energy producers elsewhere in the country and overseas.[3]

The potential for developing ethanol production capacity 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. While such ethanol production processes could provide potentially significant environmental and economic benefits, they have not been widely commercialized to date. According to the 1999 Blue Ribbon Report, biomass ethanol production now contributes only a small fraction of the amount of ethanol produced from corn, about 60 million gallons per year.

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.[4]

## B. 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*.[5] 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[6] could produce more than 1.8 billion gallons of ethanol per year.[7]

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 1 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 would likely exceed the quantity of ethanol that might be required in the Northeast over the next several years under an M*t*BE phase-out and continued oxygenate mandate.

**Table V-1**    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.

## C. STATUS OF EFFORTS TO COMMERCIALIZE CELLULOSIC BIOMASS ETHANOL PRODUCTION

The existing commercial ethanol production industry is almost entirely corn-based. It produces from 1.2 to 1.5 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 gallons per year is currently planned for start-up in the 2001-2003 timeframe. This capacity includes a 10 million gallon per year facility for producing ethanol from municipal solid waste in New York State. OFD projects that the costs of commercial-scale cellulosic ethanol production will 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).

## D. 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, and (2) vehicle emissions 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 re-growth 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[8] 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 percent relative to gasoline.[9] From an energy security standpoint, corn ethanol was found to reduce petroleum use by more than 90 percent and overall

fossil energy use by over 40 percent, 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 percent.

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'.[10] The results also depend on assumptions concerning vehicle fuel economy improvements that could be achieved on different ethanol blends. For instance, the Argonne analysis assume that a vehicle running on a 95 percent ethanol blend could achieve a 10 percent mile-per-gallon fuel economy improvement over a vehicle running on a 10 percent ethanol blend.[11]

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.

## CHAPTER V ENDNOTES

[1] Note that the material presented in this chapter is largely taken from an earlier report NESCAUM (1999) RFG/MTBE Findings and Recommendations. August.

[2] Generically, the term "biomass" refers to living (organic) matter. In an energy context, the term refers to plant material or animal waste used to generate energy. In the specific context of the ethanol/RFG/MTBE debate, biomass is typically used to refer to plant feedstocks other than corn.

[3] According to CEC, nearly 3,000 barrels per day (46 million gpy) of biomass ethanol production capacity in California is being assessed or is in planning stages; however, no new construction is underway. (California presently produces some 400 barrels per day of ethanol) Nationally, the Blue Ribbon report indicates that new biomass ethanol facilities now being planned could provide another 25,000 barrels per day (380 million gpy). The report goes on to note that new biomass ethanol production facilities can be expected to take 2 years or more to build.

[4] Much of the discussion of biomass ethanol in this section was included in NESCAUM's earlier report NESCAUM (1999) RFG/MTBE Findings and Recommendations. August.

[5] NESCAUM is unaware of any more recent studies specific to the Northeast.

[6] "Woody" biomass feedstocks include fast-growing tree species, such as poplar. Herbaceous feedstocks include non-woody species, primarily grasses such as switchgrass.

[7] 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.

[8] Wang, M., Saricks, C., Santini, D. (1999) Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions. Center for Transportation Research, Argonne National Laboratory. January.

[9] 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 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.

[10] 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.

[11] 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.