Motor Gasoline Outlook and State MTBE Bans

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1. Summary

The U.S. is beginning the summer 2003 driving season with lower gasoline inventories and higher prices than last year. Recovery from this tight gasoline market could be made more difficult by impending State bans on the blending of methyl tertiary butyl ether (MTBE) into gasoline that are scheduled to begin later this year.

Three impending State bans on MTBE blending could significantly affect gasoline markets this year. The Connecticut ban takes effect on Oct. 1, 2003, while California and New York bans follow on Jan. 1, 2004 (Connecticut may delay its ban until Jan. 1, 2004)[(1)]. It is the California ban that presents the most immediate concern. Because the original date of the California ban was Jan. 1, 2003, several California refiners are phasing out MTBE in favor of ethanol in advance of the new deadline[(2)]. Once facilities and systems have switched from MTBE to ethanol it is generally not possible to quickly revert back[(3)]. This paper reviews the supply and price issues relating to MTBE bans with a particular focus on California.

Several years ago MTBE was detected in water supplies scattered throughout the country, but predominantly in areas using reformulated gasoline (RFG)[(4)]. MTBE has apparently been making its way from leaking underground storage tanks, gasoline spills, and two-stroke gasoline engines into surface and ground water. (For more information refer to the Environmental Protection Agency web site on MTBE at http://www.epa.gov/mtbe/.) Concerns over drinking water quality have prompted 16 States and Reno, Nevada to enact legislation to restrict or prohibit the use of MTBE in gasoline.

Removal of MTBE from the gasoline pool requires not only the replacement of the lost volume but also the oxygen content, octane, and emissions-reducing properties it provides to RFG. The only oxygenate replacement that is currently considered is fuel ethanol. Although fuel ethanol has a high blending road octane value of 115 compared with 110 for MTBE (Meridian Corp., 1991), two qualities detract from its use:

1. Ethanol increases the vapor pressure (Rvp) of gasoline while MTBE has only a small effect. Because ethanol increases the vapor pressure of gasoline, low cost high vapor pressure components such as butane and pentanes must be removed from the RFG pool, which makes it more difficult and costly to produce RFG.
2. Ethanol tends to separate from gasoline if stored for an extended period of time, and if an ethanol-gasoline blend is exposed to water or water vapor (as in a pipeline), the ethanol tends to bring the water into solution and the gasoline may be rendered unusable (Environmental Protection Agency, 1996). Because of these handling problems, ethanol is shipped separately from gasoline (typically by rail car or truck but not in pipelines) and is blended with the gasoline at the distribution terminal.

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2. MTBE Supply and Demand

The blending of MTBE into motor gasoline has increased dramatically since it was first produced over 20 years ago. MTBE usage grew in the early 1980's in response to octane demand resulting initially from the phaseout of lead from gasoline and later from rising demand for premium gasoline. The oxygenated gasoline program, which began in November 1992, stimulated an increase in MTBE production from 83,000 barrels per day in 1990 to 161,000 barrels per day in 1994. The RFG program, which began in January 1995, provided a further boost to oxygenate blending. MTBE demand increased to 266,000 barrels per day by 1997.

MTBE supply and demand balances in Table 1 show that during the first few years of the Federal RFG program almost all of the MTBE consumed in the Nation was in RFG and oxygenated gasoline. Over the last few years it appears that MTBE has found its way back into the conventional gasoline pool as an octane blending component.

State bans on MTBE use could further stimulate MTBE blending into conventional gasoline for use in States without MTBE bans. It is possible that MTBE displaced from RFG in States that have implemented bans must be replaced by another clean, high octane, and low vapor pressure blendstock such as alkylate. The use of MTBE in conventional gasoline could free up alkylate. Also the decline in MTBE demand arising from the State bans could depress the market price of MTBE such that it becomes economical to increase its use as an octane blendstock. However, the use of MTBE in conventional gasoline could also be constrained as the growing number of State bans makes it difficult to maintain separate pools of conventional gasoline with and without MTBE.

Table 1. U.S. MTBE Supply and Demand Balance
(thousand barrels per day)

	1995	1996	1997	1998	1999	2000	2001
+ MTBE Production	163.5	185.1	197.1	205.5	216.2	211.5	206.7
+ MTBE Stock Draw (Build)	13.9	(3.6)	4.9	(3.9)	4.3	2.3	(1.1)
+ MTBE Gross Imports	45.1	47.7	59.9	67.8	74.8	76.5	76.6
– MTBE Gross Exports	5.9	8.3	11.6	25.9	20.7	23.8	21.2
= MTBE Net U.S. Supply	216.6	220.9	250.2	243.5	274.5	266.5	261.0
+ MTBE in RFG Imports	12.9	19.1	17.7	19.8	20.9	21.7	23.7
+ MTBE in Oxy Gas Imports	1.0	0	0	0	0	0.1	0.2
= MTBE Total Supply	230.5	240.0	267.9	263.3	295.4	288.2	285.1
– Estimated MTBE Blended in RFG and Oxy Gas (Table 2)	234.3	225.5	246.6	263.6	259.6	257.2	238.6
= Discrepancy (MTBE in conventional gasoline)	(3.8)	14.5	21.3	(0.3)	35.8	31.0	46.5

Notes:
• MTBE contained in RFG imports assumed to equal 11 percent by volume.
• MTBE contained in Oxy Gas (oxygenated gasoline) imports assumed to average 15 percent by volume.
• MTBE Net U.S. Supply = Production + Stock Draw + Gross Imports - Gross Exports.
• MTBE Total Supply = MTBE Net U.S. Supply + MTBE in RFG Imports + MTBE in Oxy Gas (oxygenated gasoline) Imports.
• Discrepancy = MTBE Total Supply - Estimated MTBE Consumption.
Source: Energy Information Administration

Only five State bans should have a significant direct effect on MTBE and gasoline markets: California, Connecticut, Kentucky, Missouri, and New York. The five States shown in Table 2 consume about 50 percent of the MTBE blended into RFG and oxygenated gasoline, and about 44 percent of all MTBE consumed in the U.S. (although this latter market share could be higher because we do not account for the volume of MTBE blended into conventional gasoline.)

The other 11 States plus Reno, Nevada, currently consume little or no MTBE. However, as noted above, the many State bans may also make it difficult to blend MTBE into the conventional gasoline pool since it may not be possible for some refiners and terminals to maintain separate pools of conventional gasoline with and without MTBE.

Table 2. Estimated MTBE Consumption in RFG and Oxygenated Gasoline by State
(thousand barrels per day)

State	MTBE Phaseout Date		MTBE Average Annual Consumption						
			1995	1996	1997	1998	1999	2000	2001
MTBE bans enacted:									
California	Jan. 1, 2004		71.2	78.8	86.5	97.3	103.6	102.4	79.7
Connecticut	Oct. 1, 2003	(11)	10.6	9.4	10.0	10.0	9.0	8.5	9.4
Kentucky	Jan. 1, 2006	(1)	1.8	2.2	2.4	2.1	2.2	2.2	2.2
Missouri	Jul. 1, 2005	(1)	0.0	0.0	0.0	0.0	2.3	3.3	3.2
New York	Jan. 1, 2004		22.7	22.0	23.7	24.4	21.4	19.7	21.1
Illinois	Jul. 24, 2004	(1, 3)	3.2	1.0	0.9	0.4	0	0	0
Colorado	May 1, 2002		0.3	0.3	0.3	0.2	0.1	0	0
Indiana	Jul. 24, 2004	(1)	0.4	0.1	0.1	0.1	0	0	0
Iowa	May 11, 2000	(1)	0	0	0	0	0	0	0
Kansas	Jul. 1, 2004	(1, 6)	0	0	0	0	0	0	0
Michigan	Jun. 1, 2003		0	0	0	0	0	0	0
Minnesota	Jul. 1, 2005	(4)	0	0	0	0	0	0	0
Nebraska	Jan. 1, 2001	(2)	0	0	0	0	0	0	0
Nevada	Jan. 1, 2004	(5)	0	0	0	0	0	0	0
Ohio	Jul. 1, 2005	(6)	0	0	0	0	0	0	0
South Dakota	July 1, 2000	(7)	0	0	0	0	0	0	0
Washington	Jan. 1, 2004	(8)	0	0	0	0	0	0	0
No MTBE bans enacted:									
Arizona		(9)	0.3	0.3	1.8	3.7	3.7	3.6	3.6
Delaware			2.6	2.2	2.6	2.8	3.0	3.0	3.0
Dist. of Columbia			1.1	0.8	0.9	0.8	0.8	0.8	0.7
Maine		(10)	3.7	3.7	3.7	3.7	0.8	0	0
Maryland			13.4	10.1	11.2	11.1	11.2	11.7	12.6
Massachusetts			16.2	16.0	16.9	16.4	14.8	16.5	16.8
New Hampshire			2.0	2.1	2.3	2.6	2.6	2.9	3.2
New Jersey			30.7	29.0	31.4	32.6	28.1	26.3	27.1
North Carolina			0.4	0	0	0	0	0	0
Pennsylvania			9.3	8.7	9.2	9.4	8.8	9.3	9.7
Rhode Island			3.8	3.5	3.4	3.5	2.9	2.9	2.6
Texas			25.9	23.7	27.0	29.2	31.2	30.3	30.5
Utah			0.0	0.0	0.1	0.1	0	0	0
Virginia			14.0	11.4	12.3	13.1	13.2	13.6	13.6

Notes:
This table does not include MTBE blended into conventional gasoline. For example, MTBE consumption in Maine in 2001 is shown in the table as zero because Maine had opted out of the reformulated gasoline program effective March 10, 1999. However, surveys conducted by the Maine Department of Environmental Protection indicate that the average MTBE concentration in gasoline sold in the State in 2001 was 2.4 volume percent (http://www.state.me.us/dep/air/mobile/fuelspage.htm), which is equivalent to about 1,250 barrels per day. Similarly, the Michigan Dept. of Agriculture reported that "in 2001, MTBE was detected in 17% of all samples obtained, with an average concentration of 4.75%." (http://www.deq.state.mi.us/documents/deq-std-MTBE1.doc).
(1) Maximum 0.5 volume percent MTBE
(2) Maximum 1.0 volume percent MTBE
(3) MTBE banned in Chicago beginning Dec. 2000
(4) Year-round State-wide oxygenated gasoline requirement with ethers limited to 0.33 volume percent after July 1, 2000, and banned after July 1, 2005.
(5) This is not a State-wide ban. Washoe County (Reno) MTBE maximum limit of 0.3 volume percent effective the same date as the California ban. Clark County (Las Vegas) adopted 10 volume percent ethanol requirement in 1999 for gasoline sold from October through March.
(6) This provision will take effect only if EPA grants the State a waiver to control or prohibit MTBE in gasoline.
(7) MTBE limited to 2.0 volume percent beginning Feb. 2000.
(8) Maximum 0.6 volume percent MTBE effective July 22, 2001
(9) Arizona Senate Bill 1504, approved by the Governor on April 28, 2000, states that it is the "policy" of the State that MTBE be phased out as soon as possible, but no later than 180 days after effective date of California ban if feasible.

(10) Maine Public Law Chapter 709 established a "goal" to eliminate MTBE in gasoline sold in the State by January 1, 2003.
(11) Connecticut may delay its ban on MTBE from Oct. 1, 2003, until Jan. 1, 2004, to make it consistent with New York State's scheduled ban. Senate Bill 840 passed the Joint House-Senate Environment Committee on March 17, 2003, and is awaiting State Senate and House action.
Source: EIA calculations. Refer to Appendix A for MTBE consumption calculation procedures.

3. Ethanol Supply

The ethanol industry is expected to be able to meet the demand for ethanol in the States that have banned MTBE without adding a single plant beyond those currently being built (Energy Information Administration, 2002a). The Renewable Fuels Association (RFA), an ethanol industry trade group, maintains a list of ethanol producers, their plant sizes, and their feedstocks. Table 3 shows that the producers on the RFA list have existing capacity of 178 thousand barrels per day, with almost all of that capacity located in the Midwest (PADD 2).

Table 3. Ethanol Production Capacity by PAD District, March 2003
(thousand barrels per day)

	Existing Capacity	Capacity Under Construction
PADD 1 (East Coast)	0.3	0.0
PADD 2 (Midwest)	175.2	32.9
PADD 3 (Gulf Coast)	1.0	0.0
PADD 4 (Rocky Mountain)	0.8	0.0
PADD 5 (West Coast)	0.6	0.0

Source: Compilation of online document: *Ethanol Production Facilities*. Renewable Fuels Association. Washington, DC, March 2003. (http://www.ethanolrfa.org/eth_prod_fac.html).

The United States imports a small quantity of fuel ethanol as well. In 2002, an average 416 barrels per day were imported from Canada, and an average 422 barrels per day were imported from Costa Rica. One reason for the low level of imports is the tariff of $0.54 per gallon that applies to most imported fuel ethanol to offset the gasoline excise tax exemption for ethanol blended gasoline (U.S. International Trade Commission, 2003).

4. Gasoline Supply

The Federal RFG program requires a minimum 2.1 percent oxygen by weight when averaging. This minimum oxygen requirement can be satisfied by blending approximately 5.5 volume percent ethanol or 11 volume percent MTBE. RFG is generally blended with the minimum required volume of ethanol or MTBE to minimize costs. Consequently, replacing MTBE with ethanol will result in a reduction of RFG volume.

When MTBE is removed and ethanol is added to gasoline, the vapor pressure (Rvp) of the gasoline blend increases and thus emissions of volatile organic compound (VOC) increase. Table 4 shows that blending 5 volume percent ethanol into 9.0 Rvp gasoline increases the Rvp to 10.1 while blending 10 volume percent MTBE increases the gasoline Rvp from 9.0 to 9.2. Because of the Rvp boost with ethanol, conventional gasoline that contains 10 volume percent ethanol (commonly called "gasohol") and sold outside of reformulated gasoline control areas is allowed a 1 pound per square inch (psi) Rvp waiver. The Environmental Protection Agency also allowed the Chicago and Milwaukee RFG areas to reduce by 2.0 percentage points (equivalent to an increase in Rvp of approximately 0.3 psi) the summertime VOC performance standard applicable to RFG blends containing 10 volume percent ethanol (66 *Federal Register* 137).

Table 4. Rvp of Gasoline/Alcohol Blends
(pounds per square inch)

Percent Gasoline	Percent Oxygenate	Vapor Pressure of Gasoline Blend With Ethanol	MTBE
100	0	9.00	9.00
95	5	10.10	9.40
90	10	10.00	9.20

Note: The vapor pressure of the gasoline blendstock before adding either MTBE or ethanol is 9.0 Rvp.
Source: Meridian Corp., 1991

To counter the increase in Rvp the gasoline blendstock that is to be combined with ethanol must be adjusted to a lower Rvp. This is accomplished by removing the light materials that boil at low temperatures and therefore have high Rvp's. These materials are generally lower cost C4 (e.g., butane) and C5 (e.g., pentane) hydrocarbons.

After C4's and C5's are reduced to achieve Rvp and 5.5 volume percent ethanol replaces 11 volume percent MTBE, the resulting distillation properties of the gasoline blend are different. The elimination of light, high-Rvp components in combination with a reduction in volume of oxygenates cause the T50 and T90 distillation temperatures for the gasoline blend to rise (the temperatures at which 50 percent and 90 percent of the gasoline boils off, respectively). These changes, in combination with less dilution of undesirable emission components, require further adjustments such as removing some of the heavier gasoline components from the base blend to meet emissions limits.

Thus, the shift to ethanol can result in a loss of volume in three ways:

- Less oxygenate volume (moving from 11 to 5.5 volume percent);
- Removal of light, high-Rvp volumes (C4's and C5's) to counter ethanol's higher Rvp; and
- Removal of heavy, high-boiling-temperature volumes to counter the loss of high-Rvp, low-boiling-temperature components and the net reduction in light oxygenate volume.

Several studies of the impact of MTBE bans on gasoline production volumes have been published. While the results of these studies vary because of different assumptions regarding the ability of refiners to adjust operations to make up for lost volume, they still reach the same conclusion that the loss of gasoline production capacity will be significant. For example, California refineries that produce only CARB (California Air Resources Board) RFG may see gasoline production fall by 10 to 17 percent (EIA, 2002b; Stillwater Assoc., 2002; and Stratco/Purvin & Gertz, 2000). The EIA (2002b) and Stillwater Assoc. (2002) cases are compared in Table 5.

Table 5. Net Change in Gasoline Supply With California MTBE Ban
(thousand barrels per day)

	Stillwater Assoc. (2002)	EIA (2002b)
MTBE removal	- 102	- 102
Ethanol addition	+ 55	+ 55
Loss of light and heavy components to balance ethanol properties	- 56	- 68
Net impact on volume	- 103	- 114
Percent reduction in total gasoline supply	- 11.0%	- 12.2%

Note: Total CARB RFG production of 935,000 barrels per day is assumed.

Increasing the ethanol content from 5.8 to 10 volume percent to make up for some of the lost volume in California may not be an option. In EIA's study, ethanol could only be increased from 5.8 to 6.0 percent before the blend failed the CARB predictive model NO_x emission test (EIA, 2002b). It was possible to get to a 7.0 percent ethanol if the refiner can also purchase additional volumes of alkylate and iso-octane, but 10 volume percent was not practically achievable.

Refiners outside of California face an additional constraint in the Mobile Source Air Toxics Rule (MSAT)[(5)]. The MSAT caps refiners at their average toxic emission level achieved in 1998-2000 to prevent "backsliding." The replacement of MTBE with ethanol contributes to an increase in toxics emissions, particularly acetaldehyde, which would require refiners to make further adjustments to their gasoline pool or possibly reduce their production of RFG[(6)].

5. Gasoline Prices

The State MTBE bans are expected to increase the cost of producing RFG and raise the pump price of gasoline. There are several factors contributing to this price increase:

- Capital investment required for transportation, storage, and blending of ethanol and ethanol-based RFG is passed on to consumers.
- Because ethanol increases the vapor pressure of gasoline, low-cost high vapor pressure components such as butane and pentanes must be removed from the RFG pool, which makes it more difficult and costly to produce RFG.
- Because approximately two gallons of MTBE are being replaced by one gallon of ethanol, the net volume loss must be made up for with some other high-octane blend component with low vapor pressure. Availability of desirable blending components such as alkylate and iso-octane is very limited.

Most estimates of higher pump prices with ethanol-blended RFG are based on long-term equilibrium models that assume sufficient lead-time for investments and perfect foresight for investors. In reality, some market participants may respond to uncertainty by delaying investment decisions, thereby creating the possibility of supply imbalance and price spikes during the MTBE phase-out. Moreover, as it becomes more difficult to produce gasoline with strict quality requirements, supply sources become fewer and more distant.

Unexpected events such as refinery outages may result in larger and longer price spikes than have been seen in the past.

Both the long-term modeling estimates of higher pump prices and potential price spikes associated with short-term market disruptions are discussed in the following two sections.

Long-Term Equilibrium Price Analysis

The State MTBE bans are projected to increase the average price of RFG by 3.6 cents per gallon in 2004, with an increase in the average national motor gasoline price of 1.8 cents per gallon, compared to a reference case with no State MTBE bans (Energy Information Administration, 2002a). Although State-level projections are not available, it is generally expected that the increase in RFG prices in California, New York and Connecticut would be significantly higher than the national average. For example, the expected RFG price increase in PADD V, which is likely to use ethanol for all of its RFG by the end of 2004, is 9 cents per gallon. Table 6 shows the impact on RFG prices and the associated ethanol supply and RFG consumption at PADD levels.

Table 6. Reformulated Gasoline Projections for 2004

	Ethanol Demand (thousand barrels per day)	**RFG Consumption** (thousand barrels per day)	**RFG Price Increase** (in 2000 dollars)
PADD I	19	1,295	$0.025/gallon
PADDs II - IV	94	807	$0.001/gallon
PADD V	65	818	$0.090/gallon
U.S.	178	2,920	$0.036/gallon

Note: The average RFG price increase in PADD I is projected to be less than the national average because New York and Connecticut only account for approximately 27 percent of the MTBE in PADD I. Other primary PADD I States, such as New Jersey, Massachusetts, Pennsylvania, Maryland, and Virginia (jointly accounting for about 56 percent of the MTBE use in PADD I), have not passed legislation to formally phase out MTBE. Thus, projections for PADD I may not represent the possible gasoline price impact on New York and Connecticut consumers.
Source: Energy Information Administration, 2003.

Short-Term Price Volatility

Prices can also rise dramatically in the very short run when there is an unexpected supply reduction such as a refinery disruption, pipeline shutdown, river flooding, etc. Price increases lower demand and are also a signal to suppliers to increase production and also obtain product from nontraditional sources.

The magnitude and duration of a price rise resulting from a supply disruption depends on the availability of alternative sources of supply and methods of delivery. For example, a loss of refining capacity on the East Coast or shutdown of a pipeline delivering gasoline from Gulf Coast refineries to the East Coast generally has small and short-term effects on prices because there are well-established alternatives available out of the Gulf Coast and Europe. California, however, presents a unique problem.

California is a unique market with three characteristics that contribute to the volatile gasoline prices that have been observed over the past few years and that are likely to continue:

1. The West Coast market is isolated and has been self-sufficient;
2. West Coast refiners are unable to keep up with demand growth; and
3. CARB RFG product specifications are more restrictive than Federal RFG.

The West Coast gasoline market receives little if any supply from outside of the region. For example, in 2002, over 99 percent of the reformulated gasoline sold in PADD V was produced within the district (compared with 54 percent in PADD I). Any demand for supply outside of the West Coast must come from nontraditional sources.

Recent growth in gasoline demand on the West Coast has not been matched by new refining capacity in the region. Stillwater Associates (2002) suggest that "it is becoming increasingly difficult for refiners to expand capacity even by small increments because of restrictions imposed by their Clean Air Act Title V operating permits, and the costs of additional emission credits in the absence of feasible offsets. Moreover...the [recent] production gains in gasoline have come largely from additional conversion of heavier components, but the remaining production of residual fuels is approaching a point of diminishing returns." This implies that a disruption in production at a West Coast refinery cannot be readily made up from an increase in production at other refineries in the region.

Finally, because CARB RFG is more restrictive than Federal RFG sold elsewhere in the Nation, emergency supplies for the West Coast must come from nontraditional sources distant from the market that do not have CARB RFG in inventory or readily available. There is not only a transportation delay moving product from Asia, Canada, South America, or the U.S. Gulf Coast, but there would also be significant production delays.

We can see the increasing volatility of California gasoline prices in Figure 1. Beginning in early 1996, when the CARB RFG program began in California, price spikes have become larger and more frequent.

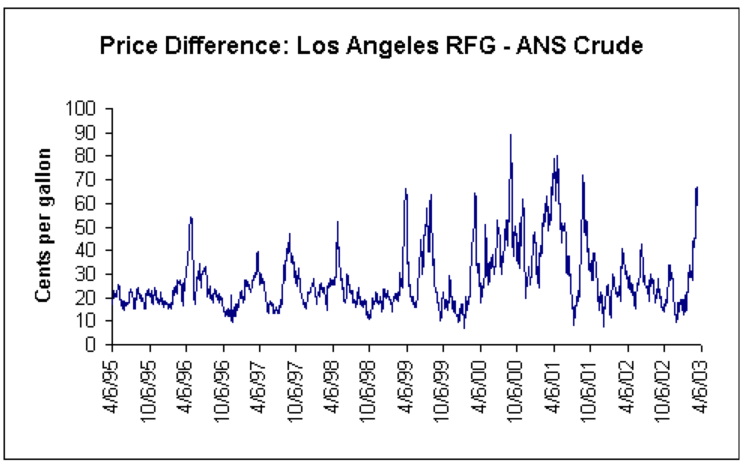

Figure 1. Spot Price Volatility of Los Angeles RFG
Source: Reuters

The MTBE ban in California may exacerbate gasoline price volatility. Meeting the CARB RFG specifications with ethanol rather than MTBE becomes more difficult for West Coast refiners and substitute supply from nontraditional sources may become more difficult to obtain. The Chicago market provides a good example of the potential increase in price volatility when MTBE is banned from gasoline. The Chicago market had effectively phased MTBE out of RFG by the end of 1998. Figure 2 shows that when the Federal Phase 2 RFG program (which required significant reductions in VOC emissions and gasoline Rvp) began in 2000, gasoline prices spiked at the start of the summer driving seasons in each of the following years.

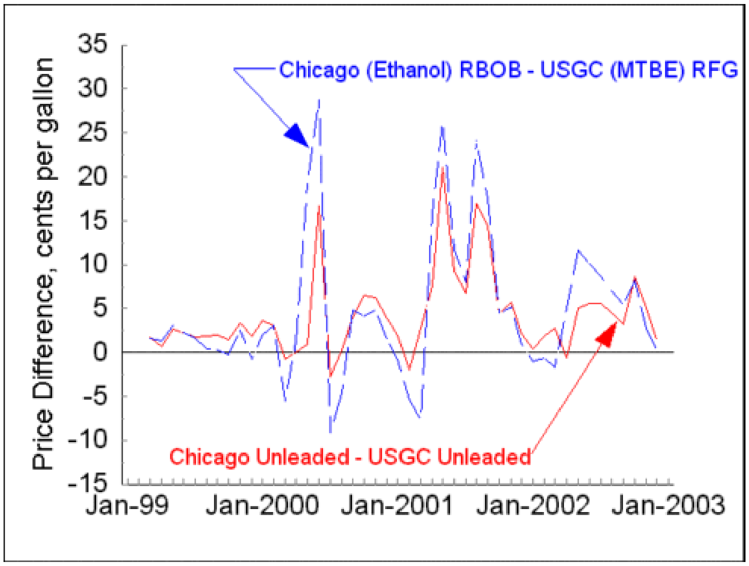

Figure 2. Chicago Pipeline Spot Prices Versus U.S. Gulf Coast (USGC)
Note: RBOB is "reformulated gasoline blendstock for oxygenate blending" (see Appendix B, Glossary of Terms.)
Source: DRI/McGraw-Hill, Platt's Oilgram Price Report, Price Average Supplement (New York, NY), various issues 1999 - 2002.

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6. Conclusion

The summer 2003 driving season may provide a hint of the challenges the petroleum industry will face over the next few years. MTBE is being banned by several States because of concerns over water quality. The cost of producing gasoline without MTBE is expected to rise by a small amount. As MTBE bans are implemented, the difficulty of producing RFG using ethanol to satisfy the required minimum oxygen content may contribute to temporary supply-demand imbalances and greater gasoline price volatility.

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7. Appendix A. Estimating MTBE Consumption by State

The calculation of MTBE consumption by State is based on the following general procedures for reformulated gasoline and oxygenated gasoline.

Reformulated Gasoline

1. We start with the Environmental Protection Agency's quality surveys of reformulated gasoline sold in each control area (EPA, *Information on Reformulated Gasoline (RFG) Properties and Emissions Performance by Area and Season*). The Federal RFG compliance program requires each control area to take random RFG samples for

analysis. The EPA reports the results of the chemical analyses as well as estimated emissions. Averages of the MTBE concentration in the RFG during the summer and winter are used to calculate the volume of MTBE sold in each State. Differentiating between summer and winter gasoline is important because oxygenate concentrations can be higher during the winter in some control areas because of Oxygenated Gasoline programs, which require 2.7 percent oxygen by weight as compared with the RFG program's 2.1 percent oxygen by weight (when averaging). Also, the use of ethanol may be higher during the winter versus the summer because of the relaxed gasoline vapor pressure restrictions.

2. MTBE concentrations in reformulated gasoline are reported in percent by weight and must be converted to percent by volume according to the formula:

Volume % oxygenate = weight % oxygenate x (density gasoline blend / density oxygenate)

For example, because MTBE is slightly heavier than gasoline during the winter, 10 weight percent MTBE will represent a slightly smaller volume percentage. The specific gravity of MTBE is 0.744 (or 6.19 pounds per gallon). The specific gravity of summertime gasoline is assumed to be 0.750 (or 6.24 pounds per gallon), and the specific gravity of winter gasoline is about 0.735 (6.12 pounds per gallon). The correction factor is the ratio of the specific gravity (or density) of gasoline to the specific gravity (or density) of MTBE. Thus, the MTBE weight-to-volume percentage correction factors are 1.0081 during the summer (0.750/0.744) and 0.9879 in the winter (0.735/0.744).

3. Since reformulated gasoline sales data are available only at the State level, MTBE concentrations reported for States with more than one control area are averaged using population weights. This implicitly assumes the mileage driven per capita and the average automobile fuel efficiency do not vary significantly across control areas. For example, Texas has two RFG areas: Houston and Dallas-Fort Worth. The July 1, 2001, population of the Houston control area was 4,795,974, while the population of the Dallas-Fort Worth area was 4,739,437, for a total Texas RFG control area population of 9,535,411. The average MTBE concentration of the winter RFG in Houston was 10.43 volume percent (10.21 weight percent) and for Dallas it was 10.10 volume percent (9.89 weight percent). A population-weighted average State MTBE concentration is then:

> (4,795,974/9,535,411) x 10.43 + (4,739,437/9,535,411) x 10.10 = 10.27 volume percent

California represents a complication in that the entire State consumes reformulated gasoline, but only four areas are mandated by the EPA and have quality surveys reported. The Los Angeles and San Diego areas were mandated by the EPA at the start of the RFG program in 1995. Sacramento was added beginning Jan. 1, 1996, and the San Joaquin Valley joined on Dec. 10, 2002. In 2001, the three Federal RFG control areas (not including the San Joaquin Valley) represented about 64 percent of the total California population, and by assumption RFG sales. Although the EPA reported that these three areas have used MTBE exclusively the same cannot be assumed for the rest of California. For example, in 2001, the Federal Highway Administration reported that 94,164 barrels per day of gasohol, which contains ethanol, was sold in the State. The volume of non-Federal RFG that contains MTBE was calculated by subtracting the gasohol sales volume from the population-weighted share of total California RFG sales in non-Federal RFG areas as shown in Table A1.

EPA product quality surveys are also missing for Phoenix, Arizona, which is a State rather than Federal RFG program. Phoenix has a winter ethanol program. For the summer Phoenix allows use of either Federal RFG or CARB RFG with no oxygen mandate. Theoretically they could be MTBE-free, but Stillwater (2002) notes that "according to the Arizona Dept. of Weights and Measures, most of the summer gasoline is [Federal RFG], and most of the gasoline provided by the LA refiners to Arizona is [Federal RFG]." We assume that MTBE consumed during the summer months in Phoenix contains an average 10 volume percent MTBE.

Table A1. Calculating the Volume of California non-Federal RFG

(barrels per day)

	1996	1997	1998	1999	2000	2001
Total CA. RFG sales	798,664	910,576	940,145	943,760	953,171	971,438
Non-Federal RFG share	x 0.368	0.368	0.368	0.367	0.366	0.366
Non-Federal RFG volume	293,908	335,092	345,974	346,360	348,860	355,546
Gasohol sales	- 110,996	108,560	72,332	59,950	68,003	94,164
Non-Federal RFG containing MTBE	182,912	226,532	273,642	286,410	280,857	261,382

Sources:
• Total California RFG Sales: Energy Information Administration, *Petroleum Marketing Annual*, Table 48, Washington, DC, various issues, http://www.eia.gov/oil_gas/petroleum/data_publications/petroleum_marketing_annual/pma_historical.html.
• Non-Federal RFG Share: population of San Diego, Los Angeles, and Sacramento control areas as a fraction of the total State population.
• Gasohol Sales: Federal Highway Administration, *Highway Statistics* annual, Table MF-33e, Washington, DC, various issues, http://www.fhwa.dot.gov/policy/ohpi/hss/hsspubs.htm.

4. Finally, the average MTBE concentration (percent by volume) in reformulated gasoline by State is then multiplied by total reformulated gasoline sales by State reported by the Energy Information Administration (*Petroleum Marketing Annual*, Table 48, "Prime Supplier Sales Volumes of Motor Gasoline by Grade, Formulation, PAD District, and State") to determine the volume of MTBE consumed.

We can compare our calculation on MTBE use in California reported in Table 2 with the survey of California refiners that was begun by the California Energy Commission (CEC) in January 2000. The CEC reports the quantity of MTBE blended at each of 13 refineries for use in the production of CARB RFG and intended for sale in the State.

Table A2. MTBE Use in California

(thousand barrels per day)

	2000	2001	2002
California Energy Commission	98.4	89.6	91.8
EIA, Table 2	102.4	79.7	n.a.

Source: CEC - California Energy Commission. *Quarterly Report Concerning MTBE Use in California Gasoline*. Sacramento, CA, various issues. http://www.energy.ca.gov/mtbe/documents/index.html#2002quarterly

Oxygenated Gasoline

The method for estimating the MTBE content of oxygenated gasoline is similar to that for reformulated gasoline except that EPA quality surveys of oxygenated gasoline are not available. However, EPA does report estimated MTBE and ethanol shares of the individual oxygenated gasoline markets (Environmental Protection Agency, State Winter Oxygenated Fuel Programs). Oxygenated gasoline sales for each control area are estimated based on State-wide sales times the control area population share. Each control area's oxygenated gasoline volume is multiplied by the MTBE market share. MTBE volumes are then calculated assuming the oxygenated gasoline contains 15 volume percent MTBE.

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8. Appendix B. MTBE Imports and Exports

Virtually all MTBE imports come into the East and West Coasts (see Table B1). The phaseout of MTBE in California should have the greatest impact on MTBE imports. California consumes about 90,000 barrels per day of MTBE. About two-thirds of California's MTBE demand is supplied by imports from Canada, Malaysia, Venezuela, and the Middle East.

Most MTBE exports leave the U.S. from the Gulf Coast (see Table B2). Opportunities for increasing MTBE exports from the U.S. may be limited. With the exception of Mexico, most MTBE exports return to the U.S. in imports of finished reformulated gasoline. For example, during 2000-2001 an average 3,279 barrels per day of MTBE was exported to Canada. During the same period an average 65,600 barrels per day of finished reformulated gasoline, containing about 6,600 barrels per day of MTBE, was shipped from Canada to the U.S.

Europe is becoming a major consumer of MTBE. The maximum allowable concentration of MTBE in the European Union is 15 percent by volume. The MTBE share of the gasoline pool in the European Union averaged about 1.9 percent in 1997 (European Fuel Oxygenates Association, 2000). Italy has been the leading European consumer of MTBE (11.1 thousand barrels per day in 1998), followed by Germany (7.6 thousand barrels per day), and Spain (7.5 thousand barrels per day) (U.S. International Trade Commission, 1999).

MTBE demand in Europe may increase as refiners there reserve substitutes for MTBE such as alkylate for the U.S. East Coast market. MTBE consumption in Europe may also grow after January 2005, when the maximum allowable aromatics concentration in gasoline is lowered from 42 percent to 35 percent by volume. Demand for high octane blending components such as MTBE may also increase in non-European Union Eastern Europe countries as a lead substitute.

Table B1. Average Annual MTBE Gross Imports, 1995 - 2002
(barrels per day)

	1995	1996	1997	1998	1999	2000	2001	2002
Imports into PADD 1 (East Coast) from:								
Brazil	0	0	145	1,340	1,477	2,189	3,266	3,425
France	940	705	3,578	4,123	4,838	1,096	219	0
Netherlands	1,027	1,158	2,025	3,573	2,827	817	2,079	940
Saudi Arabia	10,197	4,563	2,778	2,263	2,860	2,702	1,644	466
Venezuela	4,126	3,516	4,915	3,904	3,230	4,358	5,929	2,707
Virgin Islands, U.S.	0	0	855	2,252	797	0	241	137
Other Countries (Note 1)	0	117	145	0	0	284	1,477	351
Subtotals PADD 1	16,290	10,060	14,441	17,455	16,030	11,445	14,855	8,025
Total imports into PADD 3 (Gulf Coast)	945	74	121	60	0	0	288	0
Imports into PADD 5 (West Coast) from:								
Brazil	0	0	0	0	162	0	170	0
Canada	10,997	7,740	12,816	15,071	18,416	17,071	19,112	12,189
Korea, Republic Of	0	459	668	2,896	2,485	251	400	1,455
Malaysia	0	328	145	0	0	3,495	3,173	3,058
Netherlands	0	626	310	0	0	0	671	230
Qatar	0	0	0	0	0	7,940	7,244	6,022
Saudi Arabia	11,277	17,885	23,485	25,258	29,222	22,844	18,915	17,367
Singapore	0	0	1,732	570	181	36	337	285
United Arab Emirates	0	0	0	0	0	4,456	5,014	0
Venezuela	5,597	10,538	6,159	6,518	8,145	7,333	5,707	9,597
Other Countries (Note 2)	0	0	0	0	110	1,642	718	939
Subtotals PADD 5	27,871	37,577	45,315	50,312	58,721	65,068	61,460	51,142
Total U.S. Imports	45,107	47,710	59,877	67,827	74,751	76,514	76,603	59,167

Notes:
(1) Other countries shipping MTBE into PADD 1 include Belarus, Belgium, Finland, Germany, Poland, Portugal, Qatar, Spain, United Arab Emirates, and United Kingdom.
(2) Other countries shipping MTBE into PADD 5 include China, Dubai, Indonesia, South Africa, and Taiwan.
Source: Energy Information Administration (http://www.eia.gov/petroleum/data.cfm#imports).

Table B2. Average Annual MTBE Gross Exports, 1995 - 2002
(barrels per day)

	1995	1996	1997	1998	1999	2000	2001	2002
Exports from PADD 1 (East Coast) to:								
Canada	4	29	68	51	483	2,381	2,937	2,620
Mexico	0	0	0	0	0	1	0	0
Netherlands	7	0	0	6	95	139	133	115
Other	126	4	19	93	130	103	161	77
Subtotals PADD 1	138	33	87	150	708	2,624	3,232	2,812
Total Exports from PADD 2 (Midwest)	2	59	14	1	309	1	6	5
Exports from PADD 3 (Gulf Coast) to:								
Canada	105	0	0	312	92	0	1,240	3,390
Jamaica	36	43	159	497	603	868	954	1,184
Mexico	3,342	3,563	8,223	12,320	10,415	8,636	6,574	9,948
Netherlands	0	0	44	69	0	1,363	375	0
Venezuela	1,732	1,553	1,665	12,220	7,774	9,659	8,318	5,176
Other	522	3,062	1,410	359	812	613	521	1,321
Subtotals PADD 3	5,737	8,221	11,501	25,778	19,695	21,140	17,981	21,019
Total Exports from PADD 4 (Rocky Mountain)	0	0	0	0	0	0	0	0
Total Exports from PADD 5 (West Coast)	23	16	5	21	3	9	20	115
Total U.S. Exports	5,900	8,330	11,608	25,949	20,715	23,775	21,239	23,951

Source: Energy Information Administration (http://www.eia.gov/petroleum/data.cfm#imports).

9. Appendix C. Glossary of Terms

Alkylate	A high-octane product from alkylation units. An alkylation unit is a refining process for chemically combining isobutane with olefin hydrocarbons (e.g., propylene, butylene) through the control of temperature and pressure in the presence of an acid catalyst, usually sulfuric acid or hydrofluoric acid. The product, alkylate, an isoparaffin, has high octane value and is blended with motor and aviation gasoline to improve the antiknock value of the fuel.
CARB	California Air Resources Board (http://www.energy.ca.gov)
CARB RFG	Finished motor gasoline formulated for use in motor vehicles in California, the composition and properties of which meet the requirements of the California Air Resources Board.
EIA	Energy Information Administration (http://www.eia.gov)
Ethanol	Ethanol (CH_3CH_2OH) is a clear, colorless, flammable oxygenated hydrocarbon. Ethanol is typically produced chemically from ethylene, or biologically from fermentation of various sugars from carbohydrates found in agricultural crops and cellulosic residues from crops or wood. It is used in the United States as a gasoline octane enhancer and oxygenate (blended up to 10 volume percent concentration). Ethanol can also be used in high concentrations (E85) in vehicles designed for its use.
MTBE	Methyl Tertiary Butyl Ether, $(CH_3)_3COCH_3$ is an ether intended for gasoline blending as described in "Oxygenates."
MSAT	Mobile Source Air Toxics. On March 29, 2001, EPA promulgated new regulations setting standards for gasoline toxics performance levels (61 *Federal Register* 17230). Under these

new requirements, refiners must maintain their average 1998-2000 toxics performance levels, which are better than what regulations require, for benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and POM, identified as "toxic air pollutants". For more information refer to the EPA Office of Mobile Sources web page at http://www.epa.gov/otaq/toxics.htm.

Oxygenates	Substances which, when added to gasoline, increase the amount of oxygen in that gasoline blend. Ethanol, Methyl Tertiary Butyl Ether (MTBE), Ethyl Tertiary Butyl Ether (ETBE), and Tertiary Amyl Methyl Ether (TAME) are common oxygenates.
PADD	Petroleum Administration for Defense District. Geographic aggregations of the 50 States and the District of Columbia into five districts by the Petroleum Administration for Defense in 1950. These districts were originally defined during World War II for purposes of administering oil allocation. • PAD District I (East Coast): Connecticut, Delaware, District of Columbia, Florida, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, West Virginia. • PAD District II (Midwest): Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, Oklahoma, South Dakota, Tennessee, Wisconsin. • PAD District III (Southwest): Alabama, Arkansas, Louisiana, Mississippi, New Mexico, Texas, Federal Offshore Gulf. • PAD District IV (Rocky Mountain): Colorado, Idaho, Montana, Utah, Wyoming. • PAD District V (West Coast): Alaska (North Slope and Other Mainland), Arizona, California, Hawaii, Nevada, Oregon, Washington, Federal Offshore California.
RBOB	"Reformulated Gasoline Blendstock for Oxygenate Blending" is a motor gasoline blending component which, when blended with a specified type and percentage of oxygenate, meets the definition of reformulated gasoline.
RFG	Finished motor gasoline formulated for use in motor vehicles, the composition and properties of which meet the requirements of the reformulated gasoline regulations promulgated by the U.S. Environmental Protection Agency under Section 211(k) of the Clean Air Act.
Rvp	"Reid vapor pressure" is a method of determining vapor pressure of gasoline and other petroleum products. Widely used in the petroleum industry as an indicator of the volatility (vaporization characteristics) of gasoline.
VOC	Volatile organic compounds are organic compounds that participate in atmospheric photochemical reactions.

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10. End Notes

(1) Connecticut may delay its ban on MTBE from Oct. 1, 2003, until Jan. 1, 2004, to make it consistent with New York State's scheduled ban. Senate Bill 840 passed the Joint House-Senate Environment Committee on March 17, 2003, and is awaiting State Senate and House action.

(2) ConocoPhillips is reported to already have completed the switch from MTBE to ethanol. Shell, BP, and ExxonMobil indicated their intention to switch out of MTBE blended gasoline in California markets by the first quarter of 2003. Valero, ChevronTexaco, and Tesoro do not intend to complete the switch to MTBE-free gasoline until California's MTBE ban comes into effect next January (Energy Information Administration, 2003). The California Energy Commission fourth quarter 2002 survey of California refiners, however, shows no reduction in MTBE use (California Energy Commission, 2003).

(3) While separate MTBE- and ethanol-blended gasoline batches may each satisfy the RFG requirements, mixing the two may result in a blend that violates allowable VOC emissions because of the ethanol's effect on the vapor pressure of the MTBE-blended gasoline. EPA recently rejected a request from several trade groups for the California

market to allow refiners and distributors to mix ethanol and MTBE-blended gasoline during the transition (Energy Information Administration, 2003).

(4) MTBE currently provides more than 280 thousand barrels per day of volume to gasoline, which represents about 3 percent of total gasoline demand. Most of the MTBE (almost 90 percent) is used in reformulated gasoline (RFG), which makes up about one-third of the total U.S. gasoline market. RFG is gasoline that, on average, significantly reduces emissions of Volatile Organic Compounds (VOC) and Toxic Air Pollutants (TAP) relative to conventional gasolines. RFG is more difficult to produce than conventional gasoline and originally was mandated only in the nine cities with the worst smog (Los Angeles, San Diego, Chicago, Houston, Milwaukee, Baltimore, Philadelphia, Hartford, and New York City). Other areas that also have a history of smog problems voluntarily joined the RFG program. Today, RFG represents about 1/3 of gasoline consumption (Energy Information Administration, 1999)

(5) On March 29, 2001, EPA promulgated regulations setting standards for gasoline toxics performance levels (61 *Federal Register* 17230). Under these requirements, refiners must maintain their average 1998-2000 toxics performance levels, which are better than what regulations require, for benzene, formaldehyde, acetaldehyde, 1,3-butadiene, and POM, identified as "toxic air pollutants". For more information refer to the EPA Office of Mobile Sources web page at http://www.epa.gov/otaq/toxics.htm.

(6) Gasoline emissions are calculated using the EPA complex model (http://www.epa.gov/otaq/rfg.htm#models). A "baseline" fuel with 2.1 weight percent oxygen as MTBE lowers acetaldehyde emissions by 7.0 percent with a reduction in total toxics emissions of 6.9 percent. A baseline fuel with 2.1 weight percent oxygen as ethanol increases acetaldehyde emissions by 69 percent while lowering total toxics emissions by 3.5 percent. The increase in toxics emissions with ethanol versus MTBE could be higher when we account for the lower dilution effect with the smaller volume of ethanol blended to provide 2.1 weight percent oxygen.

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