Regulatory Impact Analysis: Renewable Fuel Standard Program

Chapter 2

Changes to Motor Vehicle Fuel Under the Renewable Fuel Standard Program

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In this regulatory impact analysis, we begin by describing the renewable fuel volume scenarios we used to measure the environmental and economic impacts of increased renewable fuel blending. From there we narrow our discussion in on ethanol - the predominant renewable fuel expected to be used in the future. We describe historical ethanol use, current use and our projections of future ethanol use. The discussion starts with an in-depth examination of current ethanol use. More specifically, what factors drive ethanol use and where ethanol blending currently occurs - by state, season, and fuel type. The discussion then shifts to where ethanol is expected to be used in the future. We discuss the ongoing trend in increased ethanol use, the anticipated phase-out of MTBE, and ultimately present our LP modeling results which predict where ethanol will likely be used in 2012 by PADD, season, fuel type. From there, we describe our methodology for allocating ethanol usage by state and in some cases, make distinctions on how we think ethanol would fill urban and rural areas. Once we understand how ethanol use is expected to change in the future, we measure the anticipated impacts on gasoline fuel quality (which later feeds into our emissions and air quality analyses). At the end of this chapter, we also provide a brief estimate on how increased biodiesel blending will impact diesel fuel properties.

2.1 Renewable Fuel Volume Scenarios

The Energy Policy Act of 2005 (the Energy Act or the Act) stipulates that the nationwide volumes of renewable fuel required under the Renewable Fuel Standard (RFS) program must be at least 4.0 billion gallons in 2006 and increase to 7.5 billion gallons by 2012. However, we expect that actual renewable fuel usage will exceed the RFS requirement by a significant margin. In Annual Energy Outlook 2006 (AEO 2006), the Energy Information Administration (EIA) projects that total renewable fuel demand would be 9.9 billion gallons by 2012. More specifically, EIA predicts that 9.6 billion gallons of ethanol and 303 million gallons of biodiesel would be consumed in 2012. The projected renewable fuel consumption levels were estimated using EIA's LP refinery model which was based on a crude oil price of $48/bbl. This figure is lower than today's crude oil price (tracking around $55/bbl at the time of our analysis).[17][xviii][xix] Therefore, current market conditions indicate that renewable fuel production could be even more favorable and/or prevalent in the future based on economics.[18] However, EIA's AEO

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[17] West Texas Intermediate (WTI) crude oil pricing was $59.08/bbl in November, 2006; $61.96/bbl in December, 2006; and $54.51/bbl in January 2007 according to EIA spot pricing.

[18] In AEO 2007, EIA forecasted an even higher ethanol consumption of 11.2 billion gallons by 2012. The draft report was issued on December 5, 2006, and we were unable to incorporated it into the refinery modeling used to conduct our analyses.

2006 analysis also considers the feasibility of building production facilities to accommodate for the growing renewable fuel demand. Accordingly, we interpret EIA's ethanol and biodiesel projections to be reasonable estimates considering both economics and the rate at which new plants could feasibly come on-line. As a result, in assessing the impacts of expanded renewable fuel use, we evaluated two renewable fuel usage scenarios (described in more detail below). The first represents the statutorily-required minimum and the second reflects the higher levels projected by EIA in AEO 2006. Although the actual renewable fuel volumes produced in 2012 may differ from both the required and projected volumes, we believe that these two volume scenarios represent a reasonable range for analysis purposes.

The Act also requires that at least 250 million gallons of the total renewable fuel use in 2013 and beyond meet the definition of cellulosic biomass ethanol. As described in Chapter 1, there are a number of companies planning to produce ethanol from cellulosic feedstocks and/or waste-derived energy sources that could potentially meet the definition of cellulosic biomass ethanol. Accordingly, we anticipate a ramp-up in cellulosic biomass ethanol production in the coming years. Furthermore, for analysis purposes, we have assumed that the 250 million gallon requirement would be met by 2012.

As discussed in more detail below in Section 2.2.2, we chose 2004 to represent current baseline conditions. In 2004, 3.5 billion gallons of ethanol and 25 million gallons of biodiesel were consumed in motor vehicle fuels. To compare fuel quality impacts on emissions and air quality, we created a 2012 reference case that maintained current fuel quality parameters (with the exception of sulfur) but incorporated forecasted increases in vehicle miles traveled, changes in fleet demographics, etc. The 2012 fuel reference case was developed by growing out the 2004 renewable fuel baseline according to EIA's forecasted energy growth rates. In AEO 2006, EIA predicted that gasoline demand would grow by 11.2 percent and diesel fuel demand would grow by 20.5 percent from 2004 to 2012. As a result, the 2012 reference case is based on 3.9 billion gallons of ethanol use and 30 million gallons of biodiesel use in 2012.

For our analyses, we created two 2012 control cases representing expanded renewable use – the "RFS Case" and the "EIA Case". In both cases, cellulosic biomass ethanol use was assumed to be 250 million gallons (statutory required minimum) and biodiesel use was assumed to be 303 million gallons (EIA AEO 2006 estimate). The RFS Case was designed to exactly meet the RFS program requirements considering the effects of higher equivalence values for cellulosic ethanol and biodiesel. Per § 80.1115, one gallon of cellulosic ethanol counts 2.5 times towards compliance and one gallon of biodiesel counts 1.5 times towards compliance. As a result, in the RFS Case we predict that less than 7.5 billion gallons of renewable fuel would actually be consumed in 2012. The actual volume of renewable fuel analyzed for the RFS Case was computed to be approximately 7.0 billion gallons. The EIA Case represents EIA's projections of renewable fuel use in 2012. Based on AEO 2006, the actual volume of renewable fuel

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analyzed for the EIA Case was 9.9 billion gallons. A summary of the renewable fuel volume scenarios we evaluated is found below in Table 2.1-1.

Table 2.1-1 Renewable Fuel Volume Scenarios (MMgal)

	2004	2012		
Renewable Fuel	**Base Case[a]**	**Ref Case[b]**	**RFS Case**	**EIA Case[c]**
Corn Ethanol[d]	3,548	3,947	6,421	9,388
Cellulosic Ethanol[e]	0	0	250	250
Biodiesel	25	30	303	303
Total Renewable Volume	3,573	3,977	6,974	9,941
Total Compliance Volume[f]	n/a	n/a	7,500	n/a

[a] Historical ethanol usage derived from EIA's June 2006 Monthly Energy Review. Biodiesel usage derived from "The Outlook and Impact of Biodiesel on the Oilseeds Sector" presented by John Baize at the 2006 USDA Outlook Conference.

[b] The reference case was calculated by applying the 2004-2012 gasoline/diesel energy growth rates reported in AEO 2006 to the 2004 Base Case.

[c] EIA Case based on ethanol and biodiesel energy contributions reported in AEO 2006.

[d] Includes ethanol imports.

[e] Ethanol meeting the definition of cellulosic biomass ethanol in The Act.

[f] Based on applying a 2.5 equivalence value to cellulosic biomass ethanol and a 1.5 equivalence value to biodiesel.

2.2 Current Gasoline Oxygenate Use

2.2.1 Why are oxygenates currently blended into gasoline?

The blending of oxygenates into gasoline dates back to the 1970's. However, their use greatly expanded in response to the Clean Air Act (CAA) amendments of 1990. Areas found to be out of compliance (i.e., in non-attainment) with the National Ambient Air Quality Standards (NAAQS) for ozone were required to reformulate their gasoline and use oxygenates year-round. In addition, several states began to use oxygenated fuel (oxy-fuel) in the wintertime to address carbon monoxide non-attainment. In addition, oxygenates (namely ethanol) have historically been used as a gasoline volume extender and more recently, to meet state mandates. This section summarizes the current driving forces behind gasoline oxygenate use in the U.S.

2.2.1.1 Federal Reformulated Gasoline Program

As mentioned above, areas found to be in ozone non-attainment were required to use reformulated gasoline (RFG) year-round. The federal RFG program contained a minimum oxygenate requirement as well as other fuel quality standards.[19] Adding

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[19] RFG oxygenate requirement found at 40 CFR 80.41(f). This requirement was effective for 2004 but has since been eliminated by the Energy Act Section 1504, promulgated on May 8, 2006 at 71 FR 26691.

oxygen to gasoline and reformulating other gasoline properties has helped to reduce the production of smog-forming pollutants that contribute to unhealthy ground-level ozone. Besides ozone non-attainment areas, several states/areas also opted into the RFG program (otherwise known as "opt-in"). In addition, California and Arizona have state programs that promote the use of oxygenated gasoline.

A list of the 2004 federal RFG areas and their corresponding oxygenate(s) is provided in Table 2.2-1. For the purpose of this analysis, only ethanol (ETOH) and methyl tertiary-butyl ether (MTBE) have been considered.[20]

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[20] Other low-usage oxygenates (e.g. ETBE, TAME, etc.) were assumed to be negligible for the purpose of this analysis.

Table 2.2-1. 2004 Federal RFG Areas by State[xx]

State	City	No. of Counties[a]	Type of RFG Area	Primary Oxygenate[b]
California	Los Angeles	5	Req'd	ETOH
	Sacramento	6	Req'd	ETOH
	San Diego	1	Req'd	ETOH
	San Joaquin Valley	8	Req'd	ETOH
Connecticut[c]	Hartford	6	Req'd	ETOH
	Long Island Area	1	Req'd	ETOH
	Windham County	1	Opt In	ETOH
Delaware[c]	Sussex County	1	Opt In	MTBE
	Wilmington	2	Req'd	MTBE
District of Columbia[c]	Washington DC Area	1	Opt In[d]	MTBE
Illinois	Chicago Area	8	Req'd	ETOH
Indiana	Chicago Area	2	Req'd	ETOH
Kentucky	Covington	3	Opt In	ETOH
	Louisville	3	Opt In	ETOH
Maryland	Baltimore	6	Req'd	MTBE
	Philadelphia Area	1	Req'd	MTBE
	Queen Anne/Kent Counties	2	Opt In	MTBE
	Washington DC Area	5	Opt In[d]	MTBE
Massachusetts[c]	Boston Area	10	Opt In	MTBE
	Springfield	4	Opt In	MTBE
Missouri	St. Louis	5	Opt In	ETOH
New Hampshire	Boston Area	4	Opt In	MTBE
New Jersey[c]	Atlantic City	2	Opt In	MTBE
	Long Island Area	12	Req'd	Both
	Trenton	6	Req'd	MTBE
	Warren County	1	Opt In	MTBE
New York	Poughkeepsie	2	Opt In	ETOH
	Long Island Area	11	Req'd	ETOH
Pennsylvania	Philadelphia Area	5	Req'd	MTBE
Rhode Island[c]	Providence Area	5	Opt In	MTBE
Texas	Dallas/Fort Worth	4	Opt In	MTBE
	Houston/Galveston	8	Req'd	MTBE
Virginia	Norfolk/Virginia Beach	11	Opt In	MTBE
	Richmond	7	Opt In	MTBE
	Washington DC Area	10	Opt In[d]	MTBE
Wisconsin	Milwaukee-Racine	6	Req'd	ETOH

[a] Includes partial counties.

[b] Oxygenate determination based on 2004 FHWA gasohol data and EPA fuel survey results.

[c] Entire state/district operates under the Federal RFG program.

[d] Was "opt-in" in 2004, now a required RFG area.

As shown above in Table 2.2-1, a little more than half of the Federal RFG areas (on a county-by-county basis) used MTBE as opposed to ethanol as an oxygenate in 2004. However, on a volumetric basis, more ethanol was consumed in RFG than MTBE

(2.2 billion gallons compared to 1.9 billion gallons as shown in Tables 2.1.5 and 2.1.3, respectively).

2.2.1.2 State Oxygenated Fuel Programs

In addition to the RFG program, several states require oxygenated fuel (oxy-fuel) to be used in the wintertime to address carbon monoxide (CO) non-attainment. CO is formed from the incomplete combustion of hydrocarbons (found in all gasoline blends). Production of the poisonous gas is more prevalent in oxygen-deficient environments and more harmful to human health in the wintertime due to temperature inversions.[21] Together, the winter oxy-fuel program coupled with improving vehicle emissions control systems has helped to reduce CO emissions. Many areas have and are continuing to come into attainment with the CO national ambient air quality standards (NAAQS). However, many former non-attainment areas continue to use the winter oxy-fuel program as part of a maintenance plan for remaining in compliance with the CO NAAQS. A list of the 2004 oxy-fuel areas is provided in Table 2.2-2. All oxy-fuel areas were assumed to use ethanol in 2004 based on information obtained from regional EPA offices.

Table 2.2-2. 2004 State-Implemented Winter Oxy-Fuel Programs[xxi]

Oxy-Fuel Area Location		**Oxy-Fuel Period**	**Carbon Monoxide Status**		**Winter Oxy-Fuel Program**	
State	**City**		**Designation**	**Pursuing RD[a]**	**Required**	**Part of MP[b]**
Alaska	Anchorage	11/1-2/29	Non-attainment[c]	X	X	
Arizona	Tucson	10/1-3/31	Attainment			X
	Phoenix	11/2-3/15	Non-attainment	X	X	
California	Los Angeles	10/1-2/29	Non-attainment	X	X	
Colorado	Denver/Boulder	11/1-1/31	Attainment			X
	Longmont	11/1-1/31	Attainment			X
Montana	Missoula	11/1-2/29	Non-attainment	X	X	
Nevada	Las Vegas	10/1-3/31	Non-attainment		X	
	Reno	10/1-1/31	Non-attainment	X	X	
New Mexico	Albuquerque	11/1-2/29	Attainment			X
Oregon	Portland	11/1-2/29	Attainment			X
Texas	El Paso	10/1-3/31	Non-attainment		X	
Utah	Provo/Orem	11/1-2/29	Non-attainment	X	X	
Washington	Spokane	9/1-2/29	Non-attainment[d]	X	X	

[a] Currently pursuing redesignation to CO attainment.

[b] Area is in currently in CO attainment but oxy-fuel program remains as part of maintenance plan.

[c] Area was redesignated to attainment effective 7/23/04.

[d] Area was redesignated to attainment effective 8/29/05.

2.2.1.3 Other Motivations for Blending Ethanol

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[21] Temperature inversions in the lower atmosphere are relatively common, especially during winter months in cold climates. A temperature inversion occurs when cold air close to the ground is trapped by a layer of warmer air, creating stagnation and trapping pollution close to the ground.

In addition to the RFG and oxy-fuel programs, gasoline refiners have several other motivations for blending oxygenate (namely ethanol) into gasoline. First and foremost, the state they provide gasoline to could be operating under a state ethanol mandate. In 2004, Hawaii joined Minnesota in approving a state ethanol requirement.[22] Second, blending ethanol into gasoline could help them meet their mobile source air toxics (MSAT1) performance standards as determined by the Complex Model.[23] Third, adding ethanol increases both octane and total fuel volume, thus helping refiners extend their gasoline production. Finally, and perhaps most importantly, with record-high crude oil prices and the growing availability of grain-based ethanol (especially in PADD 2), ethanol use has become increasingly economical. The 1.1 billion gallons of ethanol used in PADD 2 conventional gasoline in 2004 (refer to Table 2.2-5 in Section 2.2.2.4) is a good indicator of this trend.

In addition to the increasing availability of ethanol, consumer demand is also increasing based on the growing number of ethanol-friendly vehicles on the road. Conventional vehicles consume the majority of fuel ethanol and are limited to gasoline with 10 volume percent (vol%) ethanol (E10) or less. However, there are currently around 6 million flexible fuel vehicles (FFVs) on the road today with more being produced and sold each day[xxii]. FFVs are specifically designed to handle a wide range of gasoline/ethanol blends up to 85 vol% ethanol (E85).

2.2.2 Development of the Base Case

As discussed in 2.1, to evaluate the impacts of increased ethanol blending and decreased MTBE blending on gasoline properties (and in turn air quality), we had to create a point of comparison. To do so, we assembled a 2004 Base Case to represent current baseline conditions, i.e., current gasoline, ethanol, and MTBE use. The methodology for assembling the base case, as well as a summary of the results, is described below.

2.2.2.1 Strategy for Establishing the 2004 Base Case

For the purpose of this regulatory impact analysis, the 2004 calendar year was selected to reflect current baseline conditions. This period represented the most current year for which gasoline and oxygenate data were available and also captured the California, New York, and Connecticut MTBE bans (effective 1/1/04) while avoiding the 2005 calendar year hurricane upsets.

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[22] For analysis purposes, both states were assumed to have ethanol mandates which required 100% of the gasoline to contain 10% ethanol. However, in reality, Hawaii's ethanol mandate only requires that 85% of the gasoline contain 10% ethanol.

[23] This RFS proposal is based on MSAT1 conditions. Impacts of the recent MSAT2 rule (72 FR 8428) which removes individual refinery toxic performance standards (baselines) in exchange for a nationwide benzene standard are reflected in the analysis for that rulemaking.

The approach for assembling the 2004 base case consisted of obtaining gasoline, ethanol, and MTBE usage for all 50 states as well as the District of Columbia. As mentioned earlier, other low-volume oxygenate use (e.g., ETBE, TAME, etc.) was assumed to be negligible and thus ignored for this analysis. All ethanol-blended gasoline was assumed to contain 10 vol% ethanol, with the exception of California "RFG" (Federal RFG and California Phase 3 RFG (CaRFG3)).[24] Current California gasoline regulations make it very difficult to meet the NOx emissions performance standard with ethanol content higher than about 6 vol%. For our analysis, all California RFG was assumed to contain 5.7 vol% ethanol based on discussions with California Air Resources Board (CARB). This percentage was also applied to California RFG supplied to the Phoenix metropolitan area in the summertime under Arizona's clean burning gasoline (CBG) program.[25] Finally, all MTBE-blended gasoline was assumed to contain 11 vol% MTBE.

Total gasoline consumption was obtained from the 2004 Petroleum Marketing Annual (PMA) report published by the Energy Information Administration (EIA).[xxiii] The reported annual average sales volume for each state was interpreted as total blended gasoline (including additives, namely oxygenates). 2004 MTBE usage by state was obtained from EIA.[26,xxiv] The data received was exclusive to states with RFG programs (including Arizona's CBG program). Thus, for the purpose of the 2004 base case analysis, MTBE use was assumed to be limited to RFG areas. 2004 ethanol usage by state was derived from a compilation of data sources and assumptions. As a starting point, total domestic ethanol consumption was acquired from EIA's Monthly Energy Review published in June 2006[xxv]. State ethanol contributions originated from the 2004 Federal Highway Administration (FHWA) gasohol report[xxvi]. However, there was some ambiguity with the 2004 FHWA data. First, the total ethanol consumption did not match up with EIA's reported value (3.7 billion gallons compared to 3.5 billion gallons). Second, the gasohol (and thus ethanol) volumes were derived from potentially imprecise motor vehicle fuel tax reports.[27] And third, not all states using ethanol reported their

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[24] The small volumes of E85 (85 percent ethanol) gasoline have been ignored for this analysis.

[25] For the Base Case analysis, all Arizona CBG was classified as "RFG". In 2004, wintertime Arizona RFG was assumed to contain 10% ethanol (governed by the Phoenix oxy-fuel program). Summertime RFG was assumed to be comprised of 2/3 California RFG (containing 5.7 percent ethanol) and 1/3 PADD 3 RFG (containing either 10 percent ethanol or 11 percent MTBE in 2004).

[26] EIA reported 2004 total MTBE usage (in RFG) as 2.0 billion gallons. The reported MTBE usage was reduced from 2.0 to 1.9 billion gallons under the assumption that CA, NY, and CT implemented their state MTBE bans on time (by 1/1/04). (EIA showed small amounts of MTBE use in these states in 2004). EIA's allocation of MTBE by state was also adjusted based on fuel survey results. Most noteworthy, EIA reported MTBE usage in Arizona "RFG" as zero. However, the 2004 Phoenix fuel survey results suggest otherwise. As such, an appropriate amount of MTBE was allocated to Arizona based on the assumption that 1/3 of all summertime Arizona "RFG" resembles PADD 3 RFG (which contained some level of MTBE in 2004).

[27] The U.S. Department of Treasury requires a distinction between gasohol and gasoline on motor vehicle fuel tax reports for states with gasohol sales tax exemptions. These financial records are the source of FHWA's gasohol/ethanol data. However, since state gasohol tax exemptions have become virtually

gasohol usage so FHWA had to model-estimate 19 states' ethanol usage (accounting for 60% of the total ethanol volume). To improve upon the FHWA data, we used a series of oxygenate verification tools including knowledge of state ethanol mandates, state MTBE bans, Arizona's CBG program, and fuel survey results.[xxvii][xxviii] The state-by-state FHWA data was adjusted accordingly and allocated by fuel type (RFG, CG, and/or oxy-fuel). The summarized oxygenate results are presented throughout this section.

2.2.2.2 2004 Gasoline/Oxygenate Consumption by PADD

In 2004, 3.5 billion gallons of ethanol and 1.9 billion gallons of MTBE were blended into gasoline to supply the transportation sector with a total of 136 billion gallons of gasoline. A breakdown of the 2004 gasoline and oxygenate consumption by PADD is found below in Table 2.2-3.

Table 2.2-3. 2004 Gasoline & Oxygenate Consumption by PADD

		Ethanol			MTBE[a]		
PADD	**Gasoline MMgal**	**MMgal**	**% of Gasoline**	**% of Tot ETOH**	**MMgal**	**% of Gasoline**	**% of Tot MTBE**
PADD 1	49,193	660	1.3%	18.9%	1,360	2.8%	72.4%
PADD 2	38,789	1,616	4.2%	46.2%	1	0.0%	0.1%
PADD 3	20,615	79	0.4%	2.3%	498	2.4%	26.5%
PADD 4	4,542	83	1.8%	2.4%	0	0.0%	0.0%
PADD 5[b]	7,918	209	2.6%	6.0%	19	0.2%	1.0%
California	14,836	853	5.8%	24.4%	0	0.0%	0.0%
Total	**135,893**	**3,500**	**2.6%**	**100.0%**	**1,878**	**1.4%**	**100.0%**

[a] MTBE blended into RFG
[b] PADD 5 excluding California

As shown above, in 2004, almost half (or 46 percent) of the ethanol was consumed in PADD 2, where the majority of ethanol was produced. The next highest region of use was the State of California which accounted for nearly a quarter (or 24 percent) of domestic ethanol consumption. This makes sense since California alone accounts for over 10 percent of the nation's total gasoline consumption. And in 2004, following their MTBE ban, all fuel (both Federal RFG and CaRFG3) was presumed to contain 5.7 vol% ethanol. The next highest region of use was PADD 1 (19 percent) which makes sense considering the high concentration of RFG areas (most of which used ethanol in 2004 as shown in Table 2.2-1). The remaining 10 percent of ethanol use occurred collectively in PADDs 3, 4, and 5/

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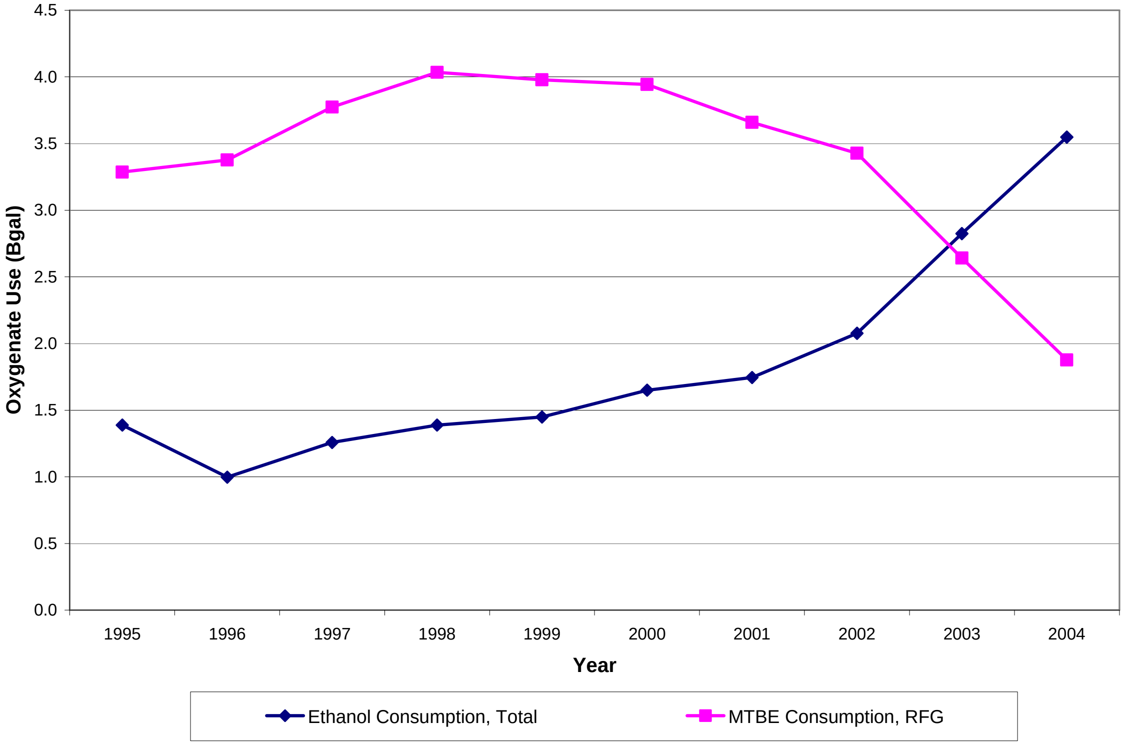
nonexistent over the past several years, gasohol reporting (namely the distinction between gasoline and gasohol) has suffered.

In 2004, total ethanol use exceeded MTBE use. Ethanol's lead oxygenate role is relatively new, however the trend has been a progression over the past few years. From 2001 to 2004, ethanol consumption more than doubled (from 1.7 to 3.5 billion gallons), while MTBE use (in RFG) was virtually cut in half (from 3.7 to 1.9 billion gallons). A plot of oxygenate use over the past decade is provided below in Figure 2.2-1.

Figure 2.2-1. Oxygenate Consumption vs. Time[xxix,xxx]



The nation's transition to ethanol is linked to states' responses to recent environmental concerns surrounding MTBE groundwater contamination. Traces of MTBE have been found in both surface and ground water in and around RFG areas. The MTBE is thought to have made its way into the water from leaking underground storage tanks, gasoline spills, and engines. Concerns over drinking water quality prompted several states to significantly restrict or completely ban MTBE use in gasoline. At the time of our analysis, 19 states had adopted MTBE bans. Ten states had bans that impacted the entire 2004 calendar year, four states had bans that impacted a portion of the year, and five states had bans that became effective in 2005 and beyond. A list of the states with MTBE bans (listed in order of phaseout date) is provided below in Table 2.2-4.

Table 2.2-4. States MTBE Bans by Phaseout Date[xxxi]

State[a]	Phaseout Date	Type of Ban[b]
Iowa	07/01/00	Partial
Minnesota	07/02/00; 07/02/05	Partial; Complete
Nebraska	07/13/00	Partial
South Dakota	07/01/01	Partial
Colorado	04/30/02	Complete
Michigan	06/01/03	Complete
California	12/31/03	Complete
Connecticut	01/01/04	Complete
New York	01/01/04	Complete
Washington	01/01/04	Partial
Kansas	07/01/04	Partial
Illinois	07/24/04	Partial
Indiana	07/24/04	Partial
Wisconsin	08/01/04	Partial
Ohio	07/01/05	Partial
Missouri	07/31/05	Partial
Kentucky	01/01/06	Partial
Maine	01/01/07	Partial
New Hampshire	01/01/07	Partial

[a] Arizona is not included because they do not have an official state MTBE ban. They adopted legislation on 4/28/00 calling for a complete phaseout of MTBE as soon as feasible but no later than six months after California's phaseout. The legislation expired on June 30, 2001, so it's not official policy. Although the state still informally encourages the phaseout of MTBE.

[b] A partial ban refers to no more than 0.5 vol% MTBE except in the case of MN (1/3%), NE (1%), and WA (0.6%)

As explained above in 2.2.2.1, all MTBE consumption was assumed to occur in reformulated gasoline in 2004. As shown in Table 2.2-3, 99 percent of MTBE use (by volume) occurred in PADDs 1 and 3. This reflects the high concentration of RFG areas in the northeast (PADD 1) and the local production of MTBE in the gulf coast (PADD 3). PADD 1 receives a large portion of its gasoline from PADD 3 refineries who either produce the fossil-fuel based oxygenate or are closely affiliated with MTBE-producing petrochemical facilities in the area.

2.2.2.3 2004 Gasoline/Oxygenate Consumption by Season

In 2004, according to EIA Petroleum Marketing Annual (PMA), approximately 40 percent of gasoline was consumed in the summertime and 60 percent was consumed in the wintertime.[xxxii] Similarly, according to EIA Monthly Energy Review June 2006, 38 percent of the ethanol was consumed in the summertime and 62 percent was consumed in the wintertime.[28,xxxiii]

Total gasoline use is higher in the wintertime because it's a longer season. The RFG regulations define summertime fuel as gasoline produced from May 1st to September 15th (4.5 months total).[29] The remaining 7.5 months are considered to be wintertime gasoline. Even though on an average per day basis summertime consumption is higher, more gasoline is still sold and consumed in the wintertime based on the length of the season.

Seasonal ethanol use follows the same general trend as gasoline. However, besides the associated correlation with seasonal gasoline consumption, there are additional reasons why 2004 ethanol use may have been higher in the wintertime. First, the oxy-fuel program requires oxygenate to be used in certain areas in the wintertime only. These same areas, which do not require oxygenate in the summer, were all presumed to use ethanol as their oxygenate (as described in 2.2.1.2). Thus, more areas use ethanol during the winter months than the summer. Secondly, there is an economic penalty associated with blending ethanol into summertime RFG. Refiners supplying summertime gasoline to RFG areas have to remove butanes and pentanes from their gasoline in order to add ethanol and still comply with the 7 psi Reid vapor pressure (RVP) requirement.

2.2.2.4 2004 Gasoline/Oxygenate Consumption by Fuel Type

According to fuel survey results, in 2004, approximately 2.2 billion gallons of ethanol were blended into reformulated gasoline and the remaining 1.3 billion gallons were used in conventional gasoline (including wintertime oxy-fuel).[xxxiv,xxxv] A breakdown of the 2004 ethanol consumption by fuel type and PADD is found in Table 2.2-5.

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[28] Aforementioned seasonal split for gasoline and ethanol based on RFG production seasons (Summer: May 1 through September 15th; Winter: January 1st through April 30th and September 16th through December 31st).

[29] We acknowledge that the aforementioned seasonal split does not exactly match the new summer/winter seasons defined in the Energy Act (Summer: April 1st through September 30th; Winter: January 1st through March 31st and November 1st through December 31st).

Table 2.2-5.
2004 Ethanol Consumption by Fuel Type (MMgal)

PADD	CG	OXY[a]	RFG[b]	Total
PADD 1	0	0	660	660
PADD 2	1,072	0	544	1,616
PADD 3	31	21	26	79
PADD 4	0	83	0	83
PADD 5[c]	45	89	75	209
California	0	0	853	853
Total	**1,149**	**193**	**2,158**	**3,500**

[a] Winter oxy-fuel programs
[b] Federal RFG plus CA Phase 3 RFG and Arizona CBG
[c] PADD 5 excluding California

As mentioned above in Section 2.2.2.1, 100 percent of the 1.9 billion gallons of MTBE blended into gasoline in 2004, was assumed to be consumed in reformulated gasoline.

2.2.2.5 2004 Gasoline/Oxygenate Consumption by State

In 2004, ethanol was blended into gasoline in 34 of the 50 states. No ethanol use was observed in the remaining 16 states: Maine, New Hampshire, Vermont, Pennsylvania, Delaware, Georgia, North Carolina, South Carolina, West Virginia, Tennessee, Oklahoma, Mississippi, Arkansas, Louisiana, Idaho, and West Virginia, nor was any ethanol used in Washington DC. A summary of 2004 ethanol usage by state is presented in Table 2.2-6. Note that a state ethanol percentage less than 10 indicates that only a percentage of the gasoline pool was blended with ethanol, not that ethanol itself was blended in less than 10 vol% (E10) proportions, except in the case of California gasoline (E5.7). Figure 2.2-2 shows the percentage of E10 by state.

The states consuming the highest volumes of ethanol in 2004 were California, Illinois, New York, Minnesota, and Ohio, respectively. With respect to gasoline use, the highest percentage of ethanol use occurred in Minnesota, Hawaii, Connecticut, Illinois, and Iowa. Four out of the five states are not surprising. The first two states have ethanol mandates and the last two are located in the "corn belt" where ethanol is produced. Connecticut's high percentage of ethanol use may come as a surprise at first glance. However, the entire state operates under the RFG program (refer to Table 2.2-1), and since they also have a state MTBE ban, ethanol is found in each gallon of gasoline.

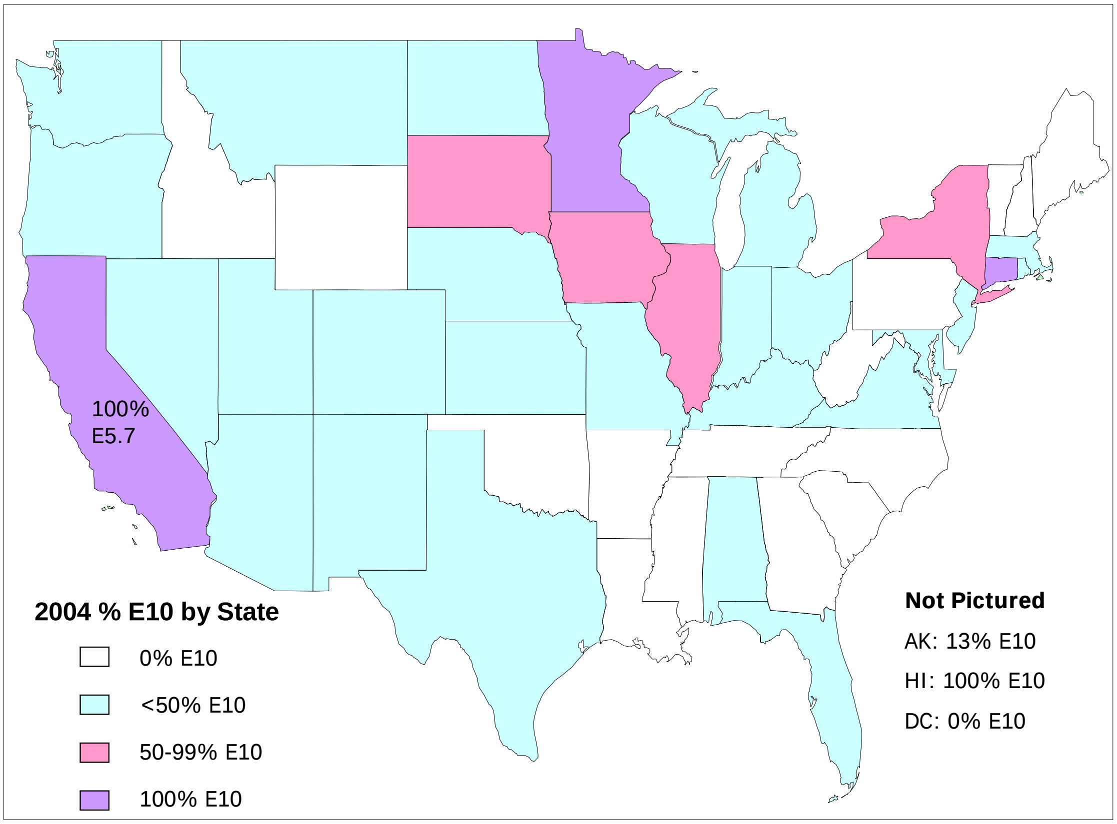
Table 2.2-6. 2004 Gasoline/Ethanol Consumption by State

		Ethanol				Ethanol	
State	**Gasoline MMgal**	**MMgal**	**% of Gasoline**	**State**	**Gasoline MMgal**	**MMgal**	**% of Gasoline**
Alabama	2,392	31	1.3%	Montana	503	1	0.2%
Alaska	302	3	1.1%	Nebraska	819	37	4.5%
Arizona	2,187	88	4.0%	Nevada	857	23	2.7%
Arkansas	1,406	0	0.0%	New Hampshire	705	0	0.0%
California	14,836	853	5.8%	New Jersey	4,235	188	4.4%
Colorado	1,999	80	4.0%	New Mexico	966	8	0.8%
Connecticut	1,522	152	10.0%	New York	5,626	301	5.4%
Delaware	449	0	0.0%	North Carolina	4,302	0	0.0%
District of Columbia	119	0	0.0%	North Dakota	350	11	3.0%
Florida[b]	8,605	0	0.0%	Ohio	5,156	192	3.7%
Georgia	4,729	0	0.0%	Oklahoma	2,158	0	0.0%
Hawaii[a]	452	45	10.0%	Oregon	1,500	31	2.1%
Idaho	632	0	0.0%	Pennsylvania	4,786	0	0.0%
Illinois	5,177	422	8.1%	Rhode Island[b]	490	0	0.1%
Indiana	3,059	148	4.8%	South Carolina	2,422	0	0.0%
Iowa	1,635	117	7.1%	South Dakota	434	24	5.5%
Kansas	1,396	41	2.9%	Tennessee	3,251	0	0.0%
Kentucky	2,177	50	2.3%	Texas	11,948	39	0.3%
Louisiana	2,287	0	0.0%	Utah	1,097	2	0.2%
Maine	757	0	0.0%	Vermont	338	0	0.0%
Maryland[b]	2,480	0	0.0%	Virginia[b]	3,920	0	0.0%
Massachusetts	2,934	18	0.6%	Washington	2,621	18	0.7%
Michigan	4,861	77	1.6%	West Virginia	772	0	0.0%
Minnesota	2,684	268	10.0%	Wisconsin	2,471	109	4.4%
Mississippi	1,617	0	0.0%	Wyoming	311	0	0.0%
Missouri	3,159	122	3.9%	**Total**	**135,893**	**3,500**	**2.6%**

[a] Hawaii was assumed to have a 100% E10 mandate in the 2004 Base Case based on RFA's Homegrown for the Homeland: Ethanol Industry Outlook 2005.

[b] Trace amounts of ethanol use (<1 MMGal) in FL, MD, RI and VA.

Figure 2.2-2. 2004 Ethanol Consumption, % E10 by State



2.2.3 Development of the 2012 Reference Case

To establish the 2012 reference case, we started with the 2004 Base Case (presented in Table 2.2-3) and grew out gasoline/oxygenate use according to the EIA AEO 2006 motor gasoline energy growth rate from 2004 to 2012.[xxxvi] Accordingly, in the resulting 2012 reference case, ethanol and MTBE use was proportional to 2004 use by both region and fuel type. A summary of the 2012 ethanol reference case is found in Table 2.2-7.

Table 2.2-7.
2012 Reference Case - Gasoline & Oxygenate Consumption by PADD (MMgal)[30]

PADD	Gasoline MMgal	Ethanol			MTBE[a]		
		MMgal	% of Gasoline	% of Tot ETOH	MMgal	% of Gasoline	% of Tot MTBE
PADD 1	54,743	735	1.3%	18.9%	1,513	2.8%	72.4%
PADD 2	43,166	1,798	4.2%	46.2%	2	0.0%	0.1%
PADD 3	22,941	88	0.4%	2.3%	554	2.4%	26.5%
PADD 4	5,055	93	1.8%	2.4%	0	0.0%	0.0%
PADD 5[b]	8,812	232	2.6%	6.0%	21	0.2%	1.0%
California	16,509	949	5.8%	24.4%	0	0.0%	0.0%
Total	**151,225**	**3,895**	**2.6%**	**100.0%**	**2,090**	**1.4%**	**100.0%**

[a] MTBE blended into RFG
[b] PADD 5 excluding California

2.2.4 Development of the 2012 Control Cases

In Section 2.2.2 we described our methodology behind building the 2004 Base Case, which was used to produce the 2012 Reference Case (described above). In this section we will describe how we developed the two 2012 control cases representing increased ethanol fuel use – the RFS Case and the EIA Case. Both control cases incorporate our knowledge of future state ethanol mandates, tax incentives, and anticipated winter oxy-fuel usage. Our analysis relied on LP modeling (described in more detail below) to determine how much ethanol would be used in each PADD, season, and fuel type. From there, we conducted post-processing to determine how much ethanol would be used on a state-by-state basis and in some cases and made predictions on how ethanol would likely fill urban and rural areas.

2.2.4.1 Forecasting Ethanol Consumption / LP Modeling Results

As mentioned earlier in Section 2.2.2.2, groundwater contamination concerns have caused many states to ban the use of MTBE in gasoline. In response to the Energy Act, all U.S. refiners are expected to eliminate the use of MTBE in gasoline by the end of 2007, and certainly prior to 2012. Ethanol consumption, on the other hand is expected to continue to grow in the future. Not only are the Energy Act's RFS requirements promoting ethanol growth, ethanol is needed to fuel the growing number of ethanol-friendly vehicles being produced as well as satisfy the growing number of state ethanol

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[30] The total ethanol volume reported in table 2.2-7 (3.895 Bgal) is slightly lower than the reference case value reported in Table 2.1-1 (3.947 Bgal). The reason for the slight discrepancy is because the numbers presented here were based off the estimated 2004 base case (3.5 Bgal) whereas the numbers presented in Table 2.1-1 were based off a more precise 2004 ethanol use (3.548 Bgal) reported by EIA in July 2006 Monthly Energy Review.

mandates (Washington, Montana, Louisiana, and Missouri recently joined Minnesota and Hawaii)[31,xxxvii,xxxviii].

Based on projections from EIA and others, it's abundantly clear that renewable fuel use (namely ethanol) is growing much faster than the RFS requirement. However quantifying future ethanol use is a difficult task. The gasoline refining industry and ethanol industry are currently undergoing a variety of changes/expansions and there is no precise way to know exactly how things are going to "fall out" in the future. Accordingly, as explained in Section 2.1, we have considered two different 2012 renewable fuel consumption scenarios to represent a reasonable range of ethanol use. For the RFS Case we modeled 6.7 billion gallons of ethanol use and for the EIA case we modeled 9.6 billion gallons (refer to Table 2.1-1). EPA is not concluding that ethanol consumption could not possibly exceed 9.6 billion gallons by 2012, but rather that this volume is a reasonable "ceiling" for our analysis.

To estimate how ethanol use would be allocated in the future, we relied on Jacob's Consultancy LP refinery modeling.[xxxix] For the Base Case and Reference Case, the LP refinery model was set up to allocate fixed volumes of ethanol/MTBE to regions consistent with our analysis of current gasoline oxygenate use (described above in Sections 2.2.2 and 2.2.3). This essentially fixed the total ethanol and MTBE use in each PADD. From there, the oxygenates were further allocated by season and fuel grade to match the oxygen content for RFG, RBOB and CBOB based on 2004 batch report data. Any leftover ethanol was allocated to CG. Based on the resulting fuel allocation, the LP model generated CG and RFG fuel properties considering the RVP effects and blending qualities of ethanol and MTBE (such properties are discussed further and utilized in Section 2.3).

For each of the future control cases, MTBE use was assumed to be zero and the amount of ethanol added to gasoline was varied. For the RFS Case, total ethanol use was fixed at 6.7 billion gallons and for the EIA Case, ethanol use was fixed at 9.6 billion gallons. For each control case, the LP model used gasoline and ethanol blending economics (e.g., ethanol distribution costs, seasonal ethanol and gasoline blendstock prices, etc.) to determine how much ethanol would be blended into gasoline by PADD, season, and fuel type. Again, the results were used to generate CG and RFG fuel properties used in Section 2.3.

Slight adjustments had to be made to the refinery modeling outputs to ensure that sufficient ethanol was supplied in the wintertime to meet the oxy-fuel requirements in PADDs 4/5. In addition, small corrections were required to ensure that ethanol blending in a given region/state did not exceed the maximum blending criteria assumed for the

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[31] The Montana state mandate requires all gasoline to contain 10 vol% ethanol once plant production ramps up to 40 MMgal/yr. The Washington state mandate requires 20% of all gasoline to contain 10 vol% ethanol by 12/1/08. Similarly, the Louisiana state mandate requires 20% of all gasoline to contain 10 vol% ethanol once plant production ramps up to 50 MMgal/yr. Finally, the Missouri state mandate requires all gasoline to contain 10 vol% ethanol by 1/1/08. At the time of our analysis, these were the only four new state ethanol mandates. However, EPA recognizes that as of 7/13/06, several others have new/additional biofuel standards pending (California, Colorado, Idaho, Illinois, Indiana, Kansas, Minnesota, New Mexico, Pennsylvania, Virginia, and Wisconsin).

analysis - 10 volume percent (vol%) ethanol nationwide, and 5.7 vol% ethanol in California. The adjusted LP refinery modeling results for the RFS and EIA control cases are summarized below in Tables 2.2-8 and 2.2-9, respectively.

Table 2.2-8.
Adjusted LP Modeling Results for the RFS Case (MMgal)

PADD	Summer Ethanol Use			Winter Ethanol Use			Total Ethanol
	CG[a]	RFG[b]	Total	CG[a]	RFG[b]	Total	
PADD 1	399	679	1,078	350	706	1,057	2,134
PADD 2	1,667	59	1,726	1,082	288	1,370	3,096
PADD 3	161	47	208	146	0	146	354
PADDs 4/5[c]	135	0	135	138	0	138	274
California	0	414	414	0	398	398	813
Total	**2,362**	**1,200**	**3,562**	**1,717**	**1,392**	**3,109**	**6,671**

[a] Includes Arizona CBG and winter oxy-fuel
[b] Federal RFG and California Phase 3 RFG
[c] PADDs 4 and 5 excluding California

Table 2.2-9.
Adjusted LP Modeling Results for the EIA Case (MMgal)

PADD	Summer Ethanol Use			Winter Ethanol Use			Total Ethanol
	CG[a]	RFG[b]	Total	CG[a]	RFG[b]	Total	
PADD 1	610	630	1,240	267	973	1,240	2,481
PADD 2	1,735	185	1,919	1,631	366	1,998	3,917
PADD 3	901	47	949	856	0	856	1,805
PADDs 4/5[c]	339	0	339	154	0	154	492
California	0	435	435	0	470	470	905
Total	**3,584**	**1,298**	**4,882**	**2,908**	**1,809**	**4,718**	**9,600**

[a] Includes Arizona CBG and winter oxy-fuel
[b] Federal RFG and California Phase 3 RFG
[c] PADDs 4 and 5 excluding California

2.2.4.2 Resulting 2012 Ethanol Consumption by PADD

Starting with the LP refinery modeling results, we segregated the Rocky Mountain (PADD 4) and West Coast (PADD 5) ethanol use (represented as an aggregate above in Tables 2.2-8 and 2.2-9) and examined the resulting ethanol allocation by region. A summary of the 2012 forecasted ethanol consumption by region (PADDs 1-5 and California) for each control case is found below in Table 2.2-10.

Table 2.2-10.
2012 Forecasted Ethanol Consumption by PADD

	6.7 Bgal RFS Case				9.6 Bgal EIA Case			
PADD	**Gasoline MMgal**	**ETOH MMgal**	**% of Gasoline**	**% of Tot ETOH**	**Gasoline MMgal**	**ETOH MMgal**	**% of Gasoline**	**% of Tot ETOH**
PADD 1	60,468	2,134	3.5%	32.0%	60,468	2,481	4.1%	25.8%
PADD 2	48,451	3,096	6.4%	46.4%	48,451	3,917	8.1%	40.8%
PADD 3	24,845	354	1.4%	5.3%	25,112	1,805	7.2%	18.8%
PADD 4	4,869	54	1.1%	0.8%	4,928	151	3.1%	1.6%
PADD 5[a]	8,537	220	2.6%	3.3%	8,626	342	4.0%	3.6%
California	16,494	813	4.9%	12.2%	16,494	905	5.5%	9.4%
Total	**163,664**	**6,671**	**4.1%**	**100.0%**	**164,078**	**9,600**	**5.9%**	**100.0%**

[a] PADD 5 excluding California

As shown above, in 2012 PADD 2 is expected to continue to dominate ethanol use. PADD 2 ethanol consumption is expected to double from 1.8 billion gallons (Bgal) in the Reference Case (refer to Table 2.2-7) to 3.1 Bgal in the RFS Case and 3.9 Bgal in the EIA Case. This represents a slight decrease in Midwest marketshare (from 46% in Reference/RFS Case to 40% in the EIA Case). The predicted shift in marketshare is attributed to the growing amount of ethanol use outside of the traditional cornbelt.

The LP modeling suggests that ethanol usage is expected to greatly increase in PADDs 1 and 3. In PADD 1, ethanol blending is expected to more than triple from 735 million gallons in the Reference Case to 2.1 Bgal in the RFS Case and 2.5 Bgal in the EIA Case. In PADD 3, ethanol use in expected to sharply increase from 88 million gallons in the Reference Case to 354 million gallons in the RFS Case and 1.8 billion gallons in the EIA Case. This projected increase in ethanol blending on the East Coast and Gulf Coast, reflects the phase out of MTBE (replacement with ethanol) as well as ethanol blending economics.

2.2.4.3 Resulting 2012 Ethanol Consumption by Season

Furthermore, we examined the resulting ethanol allocation by season. The LP refinery modeling assumes equal 182.5-day summer and winter seasons. A summary of the resulting 2012 forecasted ethanol consumption by season for each of the control cases is found below in Table 2.2-11.

Table 2.2-11.
2012 Forecasted Ethanol Consumption by Season (MMgal)

	6.7 Bgal RFS Case			9.6 Bgal EIA Case		
PADD	**Summer**	**Winter**	**Total**	**Summer**	**Winter**	**Total**
PADD 1	1,078	1,057	2,134	1,240	1,240	2,481
PADD 2	1,726	1,370	3,096	1,919	1,998	3,917
PADD 3	208	146	354	949	856	1,805
PADD 4	29	25	54	125	25	151
PADD 5[a]	106	113	220	213	128	342
California	414	398	813	435	470	905
Total	**3,562**	**3,109**	**6,671**	**4,882**	**4,718**	**9,600**

[a] PADD 5 excluding California

As shown above, ethanol usage in 2012 is expected to be slightly more prevalent in the summertime than in the wintertime. This is a shift from our 2004 Base Case (38% of ethanol use occurred in the summertime and 62% occurred in the wintertime as explained in Section 2.2.2.3), mainly because we are changing the way we define the seasons. In the Base Case we defined the seasons based on the RFG regulations (4.5 months of "summer" and 7.5 months of "winter") whereas in this 2012 forecast we are defining them based on 6 months of each season. Since gasoline consumption (gal/day) is higher in the summertime, more ethanol-blended gasoline could potentially be consumed during the summer months. However, since there is an economic penalty associated with blending ethanol into summertime gasoline (refiners have to remove butanes and pentanes to comply with the RFG RVP requirements), the result is somewhat of a seasonal balance in both the RFS Case and the EIA Case.

2.2.4.4 Resulting 2012 Ethanol Consumption by Fuel Type

In addition to providing a PADD and seasonal breakdown, The LP modeling determined how much ethanol would be used by fuel type - conventional gasoline (CG) versus reformulated gasoline (RFG). The first thing we did was allocate a portion of the CG to the required winter oxy-fuel areas.

Strategy for Allocating Ethanol to Oxy-Fuel Areas

In the 2004 Base Case, there were 14 state-implemented winter oxy-fuel programs in 11 states (summarized previously in Table 2.2-2). Of these programs, 9 were required in response to non-attainment with the CO National Ambient Air Quality Standards (NAAQS) and 5 were implemented to maintain CO attainment status. However, in the future 4 of the 9 required oxy-fuel areas are expected to be reclassified from non-attainment to attainment and discontinue using oxy-fuel in the wintertime[32]. These areas are: Anchorage, AK; Las Vegas, NV; Provo/Orem, UT; and Spokane, WA. In addition,

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[32] Based on conversations with state officials and regional EPA officials.

Colorado is expected to discontinue using winter oxy-fuel in Denver/Boulder and Longmont to maintain CO attainment status. The use of oxy-fuel in the above-mentioned areas is expected to discontinue by 2012 or sooner. With the removal of these 6 state-implemented programs, that leaves a total of 8 oxyfuel areas in Tucson and Phoenix, AZ; Los Angeles, CA; Missoula, MT; Reno, NV; Albuquerque, NM; Portland, OR; and El Paso, TX. We assumed that these areas would continue to blend 10 vol% ethanol into their gasoline for their entire winter oxy-fuel period (duration varies by area, six month maximum) in the 2012 control cases.

Once a portion of the conventional gasoline ethanol was allocated to meet winter oxy-fuel requirements, this gave use a PADD-by-PADD breakdown of ethanol use by conventional gasoline, oxy-fuel, and reformulated gasoline as shown below in Table 2.2-12.

Table 2.2-12.
2012 Forecasted Ethanol Consumption by Fuel Type (MMgal)

	6.7 Bgal RFS Case				**9.6 Bgal EIA Case**			
PADD	**CG[a]**	**OXY[b]**	**RFG[c]**	**Total**	**CG[a]**	**OXY[b]**	**RFG[c]**	**Total**
PADD 1	750	0	1,385	2,134	877	0	1,603	2,481
PADD 2	2,749	0	347	3,096	3,366	0	551	3,917
PADD 3	283	24	47	354	1,733	24	47	1,805
PADD 4	54	0	0	54	151	0	0	151
PADD 5[d]	106	113	0	220	228	113	0	342
California	0	0	813	813	0	0	905	905
Total	**3,942**	**137**	**2,592**	**6,671**	**6,356**	**137**	**3,107**	**9,600**

[a] Conventional gasoline including Arizona CBG
[b] Winter oxy-fuel programs
[c] Federal RFG plus CA Phase 3 RFG
dPADD 5 excluding California

However, more post-processing was required to determine how much ethanol would be used on a state-by-state basis to feed into the emissions and air quality analyses. We begin the latter part of this discussion by explaining how we allocated the RFG ethanol to specific RFG areas and how we allocated the CG ethanol to specific states/regions considering state ethanol mandates and the economic favorability of ethanol blending

Strategy for Allocating Ethanol Among RFG

In the 2004 Base Case, there were 18 states/districts with RFG programs covering a total of 175 counties in 36 areas (summarized previously in Table 2.2-1). For our analysis of 2012 ethanol use, we assumed that the number of RFG areas would not change and accordingly, that the RFG fuel contribution to the gasoline pool would remain the same. However, we considered the amount of ethanol added to RFG to be a variable, as discussed below.

In the past, all RFG areas were required to use a minimum amount of oxygenate in their reformulated gasoline year-round, as discussed earlier in 2.2.1.1. However, effective May 5, 2006, EPA removed the RFG oxygenate requirement in response to the Act.[xl] Although the oxygenate requirement has already been eliminated, many refiners are still operating under contracts with ethanol blenders. As such, refiners true response to the removal of the oxygenate requirement is relatively unknown at this time. While it is difficult to predict exactly how each refinery supplying an RFG area would behave, the LP modeling has attempted to do so.

The modeling suggests that some refineries will continue to blend ethanol into RFG (or even increase blending) in 2012 based on octane, volume, and/or toxic performance requirements. Some RFG producers may decidedly replace MTBE with ethanol while others may pare back or discontinue ethanol use all together. A summary of the 2012 forecasted RFG ethanol consumption (by season) for each control case is found below in Table 2.2-13.

Table 2.2-13.
2012 Forecasted RFG Ethanol Consumption (MMgal)[33]

		6.7 Bgal RFS Case				**9.6 Bgal EIA Case**				
		Summer		**Winter**		**Summer**		**Winter**		
PADD/State	**Seasonal RFG Use MMgal[a]**	**ETOH MMgal**	**% of Gasoline**	**ETOH MMgal**	**% of Gasoline**	**ETOH MMgal**	**% of Gasoline**	**ETOH MMgal**	**% of Gasoline**	**Average % ETOH in RFG**
PADD 1	11,380	679	6.0%	706	6.2%	630	5.5%	973	8.5%	6.6%
PADD 2	3,661	59	1.6%	288	7.9%	185	5.0%	366	10.0%	6.1%
PADD 3 / TX	2,939	47	1.6%	0	0.0%	47	1.6%	0	0.0%	0.8%
PADD 5 / CA[b]	8,247	414	5.0%	398	4.8%	435	5.3%	470	5.7%	5.2%
Total	**26,227**	**1,200**	**4.6%**	**1,392**	**5.3%**	**1,298**	**4.9%**	**1,809**	**6.9%**	**5.8%**

[a] Equal amounts of reformulated gasoline assumed to be used in the summer and winter seasons.
[b] Includes Federal RFG and CA Phase 3 RFG

As shown above, the modeling suggests that more ethanol would be consumed in RFG in the EIA Case in the presence of more ethanol. The modeling also suggests that the greatest ethanol marketshare would occur in California RFG (5.2 vol% ethanol on average across both cases/seasons, or 91% E5.7). The next highest areas of RFG use would be PADD 1 (6.6 vol% ethanol on average, or 66% E10) followed by PADD 2 (6.1 vol% ethanol on average, or 61% E10). Little ethanol blending was predicted to occur in Texas RFG (0.8% ethanol or 8% E10).

In both control cases, more ethanol was predicted to be blended into wintertime RFG. As discussed earlier, this makes sense because in order to meet the RVP requirements pertaining to summertime RFG (7 psi), refiners have to remove butanes and

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[33] Gasoline consumed in the greater Phoenix metropolitan area under the Arizona Clean Burning Gasoline (CBG) Program, has not been considered "RFG" by the LP refinery modeling and thus discussed in the conventional gasoline section.

pentanes to accommodate for ethanol blending (which increases overall gasoline volatility). As such, in the absence of an RVP waiver (which exists exclusively for summertime CG), refiners are less inclined to blend ethanol into summertime RFG.

To allocate the RFG ethanol (aggregated by PADD and season in Table 2.2-13) by state/RFG area, we assumed that each region would behave uniformly with the exception of PADD 1 (discussed in more detail below). For example, consider PADD 2 summertime RFG. In the RFS Case, RFG in Chicago, Louisville, Milwaukee, etc. would all contain 1.6% ethanol on average. Or more accurately, 16% of all the gasoline consumed within PADD 2 RFG areas would contain 10% ethanol.

However, based on our knowledge of the refining industry and distribution patterns, we did not assume that PADD 1 RFG would be uniform in ethanol content. The LP modeling assumes that the RFG produced in PADD 1 contains ethanol but the RFG produced in PADD 3 and shipped to PADD 1 does not. RFG from PADD 3 comes up the Colonial Pipeline and passes through Virginia, Washington DC and Maryland on its way to Pennsylvania and New York. With the exception of a small Yorktown refinery, the southernmost refineries in PADD 1 are located around the Philadelphia area. However, there is no cheap way to send fuel south. Therefore, the RFG coming from PADD 3 is likely to completely fulfill the RFG demand in Virginia, Washington DC and Maryland. Beyond Maryland, the fuel from PADD 1 refineries is sold along with any leftover PADD 3 RFG, as distribution costs are roughly the same from Philadelphia north. As a result, the Virginia, Washington DC and Maryland RFG areas were assumed to receive less ethanol (in most cases zero E10) than the other RFG areas located in PADD 1. A summary of the resulting RFG ethanol distribution by state is found below in Table 2.2-14.

Table 2.2-14.
2012 RFG Ethanol Distribution by State

PADD/State	6.7 Bgal RFS Case		9.6 Bgal EIA Case	
	Summer	Winter	Summer	Winter
PADD 1	78% E10 in all states except DC, MD, VA (0% E10)	81% E10 in all states areas except DC, MD, VA (0% E10)	73% E10 in all states except DC, MD, VA (0% E10)	100% E10 in all states except DC, MD, VA (39% E10)
PADD 2	16% E10 in all states	78% E10 in all states	51% E10 in all states	100% E10 in all states
PADD 3/TX	16% E10 in TX	0% E10 in TX	16% E10 in TX	0% E10 in TX
PADD 5/CA	88% E5.7 in CA	85% E5.7 in CA	93% E5.7 in CA	100% E5.7 in CA

Strategy for Allocating Ethanol Among CG

The above-mentioned oxy-fuel requirements combined with state ethanol mandates created a “floor” for conventional gasoline ethanol use within each PADD. This essentially forced a specific amount of ethanol to be used in wintertime CG in PADDs 3 and 5 and a specific amount of ethanol to be added year-round in Minnesota, Montana, and Missouri (100% E10 mandates); Hawaii (85% E10 mandate); as well as Washington and Louisiana (20% E10 mandates).

To determine how the remaining ethanol would be allocated to the leftover conventional gasoline, we devised a systematic way to allocate ethanol by state/area. Since the primary motivation to blend (or not blend) ethanol is expected to be economic, we devised a way to rank CG areas, on a state-by-state and urban/rural basis, as to the economic favorability of ethanol blending. This was done by calculating an ethanol margin, which is equal to gasoline price minus ethanol delivered price. Ethanol delivered price is equal to ethanol plant gate price plus transportation costs minus any additional state plus other adjustments (explained below). The greater the ethanol margin, the greater the economic incentive and the more likely ethanol is to be used in that area.

At the time the analysis was carried out, ethanol plant gate price was taken from an older EIA NEMS model. However, since this price was assumed to be the same for all ethanol, the actual value is not important when trying to estimate relative allocation preferences between areas. All ethanol blending was assumed to be done at 10 volume percent. The gasoline prices for each state were the weighted average rack price of all conventional grades and all months, taken from EIA Petroleum Marketing Annual 2004.[xli]

Ethanol distribution costs were taken from figures given in the documentation for the EIA NEMS model, and are based on a 2002 study by DAI, Inc.[xlii] For the purpose of this consumption analysis, all ethanol was assumed to be produced in the Midwest in census divisions 3 and 4 (corresponding closely to PADD 2). This is largely consistent with the production analysis presented in Chapter 1 of the RIA. While the results of the production analysis do not completely coincide with this assumption (as shown in Table 1.2-15, about 86 percent of the total ethanol plant capacity is expected to originate from PADD 2 in 2012 and the rest would originate from other areas throughout the country), this simplifying assumption is still very reasonable.

Ethanol consumed within census divisions 3 and 4 was assumed to be transported by truck, while distribution outside of those areas was via rail, ship, and/or barge. A single average distribution cost for each destination census division was generated by weighting together the 2012 freight costs given for each mode in both census divisions 3 and 4 according to their volume share. These cent per gallon figures were first adjusted upward by 10 percent to reflect higher energy prices, and then additional adjustments were applied to some individual states based on their position within the census division. In the cases of Alaska and Hawaii, differences in ethanol delivery prices from the mainland were inferred from gasoline prices. Table 2.2-15 shows the gasoline price and ethanol distribution cost for each state as used in this analysis.

Table 2.2-15.
Gasoline Price & Ethanol Distribution Costs[34]

State	Gasoline Rack Price (c/gal)	ETOH Distribution Cost (c/gal)
Alabama	123.2	7.2
Alaska	157.0	41.5
Arizona	138.0	15.4
Arkansas	123.3	7.3
Colorado	129.5	10.4
Florida	124.9	8.4
Georgia	125.8	11.4
Hawaii	151.7	36.5
Idaho	134.2	15.4
Illinois	125.7	4.4
Indiana	125.6	5.4
Iowa	127.5	3.4
Kansas	124.3	4.4
Kentucky	125.9	6.2
Louisiana	123.1	7.3
Maine	125.5	13.4
Maryland	124.8	11.4
Michigan	126.5	6.4
Minnesota	127.4	4.4
Mississippi	123.0	6.2
Missouri	126.0	4.4
Montana	130.5	13.4
Nebraska	126.0	4.4
Nevada	141.6	16.4
New Hampshire	125.3	12.4
New Mexico	128.4	12.4
New York	126.0	11.4
North Carolina	124.4	11.4
North Dakota	127.7	5.4
Ohio	126.2	5.4
Oklahoma	123.4	8.3
Oregon	133.8	16.5
Pennsylvania	126.1	8.4
South Carolina	124.9	11.4
South Dakota	127.8	4.4
Tennessee	124.5	6.2
Texas	122.5	10.3
Utah	132.3	13.4
Vermont	127.3	12.4
Virginia	123.4	11.4
Washington	132.1	16.5
West Virginia	125.8	11.4
Wisconsin	125.2	4.4
Wyoming	130.4	12.4

As the final step in the calculation, subsidies and other adjustments were applied. The federal blending credit of 51 cents per gallon was given to all areas, and five state retail incentives were included as follows (all cents per gallon of ethanol): Iowa, 29.5; Illinois, 20.1, South Dakota, 20; Maine: 7.5; Oklahoma, 1.6.[35][xliii]

In addition to state subsidies, small penalty adjustments were made for distributing ethanol into rural areas in several states (as presented in Table 2.2-16). The reasoning behind this is that when large shipments of ethanol come from the Midwest by barge, ship, or rail, they will be unloaded initially at large terminals near metropolitan areas. Further storage and handling will be required to allow smaller quantities to be distributed via truck into rural areas. Several states have gasoline pipelines that traverse them with connections at various points, helping to reduce distribution burdens, but ethanol is not expected to be shipped via pipeline. Overall, the largest adjustments were applied to the Rocky Mountain states since they are generally larger in area and additional expense is required to transport freight through higher elevations and rugged terrain. Smaller adjustments were applied to states that are smaller, flatter, or have navigable water access on one or more sides. The states that do not appear on this list are either located in the Midwest (where ethanol is produced and readily available to virtually all areas at similar costs) or are small northeast states not believed to have significant differences between rural and urban distribution costs.

Table 2.2-16.
Adjustment for Ethanol Distribution into Rural Areas

States	Rural Area Adjustment (c/gal)
OH	2
AL, AR, FL, GA, KY, LA, ME, MS, NC, NY, OK, OR, PA, SC, TN, VA, WA, WV	4
AK, AZ, CO, ID, NM, NV, UT, WY, TX	5

To determine which in-use areas/counties would receive urban versus rural ethanol distribution pricing based on the economies of scale described above, we looked to the U.S. Census Bureau which considers population density and other factors.

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[34] The following states have intentionally been excluded from this CG gasoline/ethanol cost table because they do not consume any CG (100% RFG): CA, CT, DC, DE, MA, NJ, RI.

[35] EPA acknowledges that other states are considering (or may have even approved) retail pump incentives for gasohol. However, at the time this consumption analysis was completed, these were the only five states offering retail pump incentives that were likely to be applicable in 2012.

Metropolitan Statistical Areas (MSAs) served as the starting point for determining the areas within a state that would be considered "urban". MSAs are geographic entities defined by the U.S. Office of Management and Budget (OMB) for use by federal statistical agencies in collecting, tabulating, and publishing federal statistics. An MSA is defined as having a core urban area of 50,000 or more people. Each MSA consists of one or more counties including the counties contained the core urban area, as well as any adjacent counties that have a high degree of social and economic integration with the urban core. For the purposes of this analysis, we only considered MSAs with populations greater than 1 million people, or other areas having special qualifications. Such qualifications include MSAs with less than 1 million people that happen to be the largest MSA in a less-populated state (i.e. Montana and Wyoming), or other MSAs deemed likely to receive ethanol by rail based on proximity to major rail lines.

Once the urban counties for each state were determined, county-level vehicle miles traveled (VMT) from 2002 were used (as a surrogate for fuel consumption) to weight the urban counties' approximate fuel demand. Expressing the urban VMT as a function of statewide VMT gave us the percentage of ethanol demand that would be considered eligible for an urban ethanol distribution cost (values presented in Table 2.2-15). The remaining percentage of ethanol demand was considered to be "rural" and subject to the ethanol blending penalty adjustments found in Table 2.2-16.

Considering the urban/rural split for each state and the resulting ethanol margin (ethanol delivered price minus gasoline production cost), we came up with the resulting ranking system for distributing ethanol into conventional gasoline. For PADD 1, refer to Table 2.2-17; PADD 2, refer to Table 2.2-18, PADD 2, Table 2.2-19; and PADDs 4/5, Table 2.2-20. The summer and winter percentages are the same for each urban/rural area with the exception of states containing winter oxy-fuel areas. For these states, winter oxy-fuel was deducted from the winter urban fuel since this volume of gasoline was already accounted for (refer to Table 2.2-12).

Table 2.2-17.
Precedence for Adding ETOH to PADD 1 CG

State	Rural / Urban	Ethanol Margin (c/gal)	PADD 1 Precedence	% of CG Volume	
				Summer	Winter
ME	u	50.6	1	35.7%	35.7%
PA	u	48.7	2	44.7%	44.7%
FL	u	47.5	3	59.9%	59.9%
ME	r	46.6	4	64.3%	65.3%
VT	-	45.9	5	100.0%	100.0%
NY	u	45.6	6	67.8%	67.8%
GA	u	45.4	7	51.2%	51.2%
WV	u	45.4	8	21.1%	21.1%
PA	r	44.7	9	55.3%	55.3%
SC	u	44.5	10	20.2%	20.2%
MD	-	44.4	11	100.0%	100.0%
NC	u	44.0	12	14.7%	14.7%
NH	-	43.9	13	100.0%	100.0%
FL	r	43.5	14	40.1%	40.1%
VA	u	43.0	15	63.9%	63.9%
NY	r	41.6	16	32.3%	32.3%
WV	r	41.4	17	78.9%	78.9%
GA	r	41.4	18	48.8%	48.8%
SC	r	40.5	19	79.8%	79.8%
NC	r	40.0	20	85.3%	85.3%
VA	r	39.0	21	36.1%	36.1%

Table 2.2-18.
Precedence for Adding ETOH to PADD 2 CG

State	Rural / Urban	Ethanol Margin (c/gal)	PADD 2 Precedence	% of CG Volume	
				Summer	Winter
IA	-	84.6	1	100.0%	100.0%
SD	-	74.4	2	100.0%	100.0%
IL	-	72.4	3	100.0%	100.0%
ND	-	53.3	4	100.0%	100.0%
NE	-	52.6	5	100.0%	100.0%
OH	u	51.8	6	37.7%	37.7%
WI	-	51.8	7	100.0%	100.0%
IN	-	51.2	8	100.0%	100.0%
MI	-	51.1	9	100.0%	100.0%
KS	-	50.9	10	100.0%	100.0%
KY	u	50.7	11	10.2%	10.2%
OH	r	49.8	12	62.3%	62.3%
TN	u	49.3	13	38.4%	38.4%
OK	u	47.7	14	29.9%	29.9%
KY	r	46.7	15	89.8%	89.8%
TN	r	45.3	16	61.6%	61.6%
OK	r	43.7	17	70.1%	70.1%

Table 2.2-19.
Precedence for Adding ETOH to PADD 3 CG

State	Rural / Urban	Ethanol Margin (c/gal)	PADD 3 Precedence	% of CG Volume	
				Summer	Winter
MS	u	47.8	1	6.8%	6.8%
NM	u	47.0	2	31.3%	16.0%
AR	u	47.0	3	26.4%	26.4%
AL	u	47.0	4	31.2%	31.2%
LA	u	46.8	5	16.7%	16.7%
MS	r	43.8	6	93.2%	93.2%
TX	u	43.2	7	61.8%	58.2%
AR	r	43.0	8	73.7%	73.7%
AL	r	43.0	9	68.8%	68.8%
LA	r	42.8	10	63.3%	63.3%
NM	r	42.0	11	68.7%	68.7%
TX	r	38.2	12	38.2%	38.2%

Table 2.2-20.
Precedence for Adding ETOH to PADDs 4/5 CG

State	Rural / Urban	Ethanol Margin (c/gal)	PADDs 4/5 Precedence	% of CG Volume	
				Summer	Winter
NV	u	56.2	1	57.8%	49.2%
AZ	u	53.6	2	55.2%	5.4%
NV	r	51.2	3	42.2%	42.2%
CO	u	50.1	4	48.6%	48.6%
UT	u	49.9	5	38.7%	38.7%
ID	u	49.8	6	32.3%	32.3%
WY	u	49.0	7	11.6%	11.6%
AZ	r	48.6	8	44.8%	44.8%
OR	u	48.3	9	38.2%	1.4%
WA	u	46.6	10	43.6%	43.6%
AK	u	46.5	11	36.4%	36.4%
HI	-	46.2	12	15.0%	15.0%
CO	r	45.1	13	51.4%	51.4%
UT	r	44.9	14	61.3%	61.3%
ID	r	44.8	15	67.7%	67.7%
OR	r	44.3	16	61.8%	61.8%
WY	r	44.0	17	88.5%	88.5%
WA	r	42.6	18	36.4%	36.4%
AK	r	41.5	19	63.6%	63.6%

2.2.4.5 Resulting 2012 Gasoline/Oxygenate Consumption by State

Applying the CG order of precedence tables to the remaining conventional gasoline ethanol (less state mandated and winter oxy-fuel volumes) and factoring in the RFG ethanol distribution (described above in 2.2.4.4), we came up with an ethanol distribution by state for each control case. The resulting state-by-state ethanol distribution is summarized below in Table 2.2-21 and a graphical representation for each control case is provided in Figures 2.2-3 and 2.2-4 below.

Table 2.2-21.
2012 Forecasted Ethanol Consumption by State

(continued on next page)

		6.7 Bgal RFS Case			9.6 Bgal EIA Case		
State	**Abbrv**	**Gasoline MMgal**	**ETOH MMgal**	**% of Gasoline**	**Gasoline MMgal**	**ETOH MMgal**	**% of Gasoline**
Alabama	AL	2,869	90	3.1%	2,910	291	10.0%
Alaska	AK	324	0	0.0%	327	0	0.0%
Arizona	AZ	2,377	123	5.2%	2,397	149	6.2%
Arkansas	AR	1,686	44	0.0%	1,710	171	10.0%
California	CA	16,494	813	4.9%	16,494	905	5.5%
Colorado	CO	2,143	0	0.0%	2,169	57	2.6%
Connecticut	CT	1,827	146	8.0%	1,827	158	8.6%
Delaware	DE	538	43	0.0%	538	46	8.6%
District of Columbia	DC	143	0	0.0%	143	3	2.0%
Florida	FL	10,734	521	4.8%	10,734	474	4.4%
Georgia	GA	5,899	0	0.0%	5,899	12	0.2%
Hawaii	HI	484	0	0.0%	490	42	8.5%
Idaho	ID	677	0	0.0%	686	12	1.7%
Illinois	IL	6,737	454	6.7%	6,737	570	8.5%
Indiana	IN	3,820	352	9.2%	3,820	368	9.6%
Iowa	IA	2,017	202	10.0%	2,017	202	10.0%
Kansas	KS	1,722	86	5.0%	1,722	172	10.0%
Kentucky	KY	2,742	42	1.5%	2,742	72	2.6%
Louisiana	LA	2,743	99	0.0%	2,782	278	10.0%
Maine	ME	944	34	0.0%	944	64	6.8%
Maryland	MD	2,990	0	0.0%	2,990	52	1.7%
Massachusetts	MA	3,522	281	8.0%	3,522	304	8.6%
Michigan	MI	5,995	346	5.8%	5,995	599	10.0%
Minnesota	MN	3,310	331	10.0%	3,310	331	10.0%
Mississippi	MS	1,940	25	0.0%	1,968	197	10.0%
Missouri	MO	3,986	343	8.6%	3,986	372	9.3%
Montana	MT	539	54	10.0%	546	55	10.0%
Nebraska	NE	1,010	101	10.0%	1,010	101	10.0%
Nevada	NV	920	6	0.7%	931	52	5.6%
New Hampshire	NH	855	50	0.0%	855	54	6.3%
New Jersey	NJ	5,083	406	8.0%	5,083	439	8.6%
New Mexico	NM	1,152	35	3.0%	1,167	109	9.3%
New York	NY	6,876	289	4.2%	6,876	423	6.1%
North Carolina	NC	5,366	0	0.0%	5,366	0	0.0%
North Dakota	ND	432	43	10.0%	432	43	10.0%
Ohio	OH	6,358	438	6.9%	6,358	636	10.0%
Oklahoma	OK	2,661	0	0.0%	2,661	28	1.0%
Oregon	OR	1,623	34	2.1%	1,638	34	2.1%
Pennsylvania	PA	5,909	318	0.0%	5,909	328	5.6%
Rhode Island	RI	588	47	8.0%	588	51	8.6%
South Carolina	SC	3,022	0	0.0%	3,022	0	0.0%
South Dakota	SD	535	54	10.0%	535	54	10.0%
Tennessee	TN	4,010	37	0.0%	4,010	78	2.0%
Texas	TX	14,454	62	0.4%	14,574	759	5.2%
Utah	UT	1,176	0	0.0%	1,191	25	2.1%
Vermont	VT	422	0	0.0%	422	21	5.0%
Virginia	VA	4,786	0	0.0%	4,786	52	1.1%
Washington	WA	2,810	56	2.0%	2,843	64	2.3%
West Virginia	WV	964	0	0.0%	964	0	0.0%
Wisconsin	WI	3,117	268	8.6%	3,117	291	9.3%
Wyoming	WY	333	0	0.0%	337	2	0.6%
Total		**163,664**	**6,671**	**4.1%**	**164,078**	**9,600**	**5.9%**

**Figure 2.2-3. 2012 Forecasted Ethanol Consumption
6.7 Bgal RFS Case, % E10 by State**

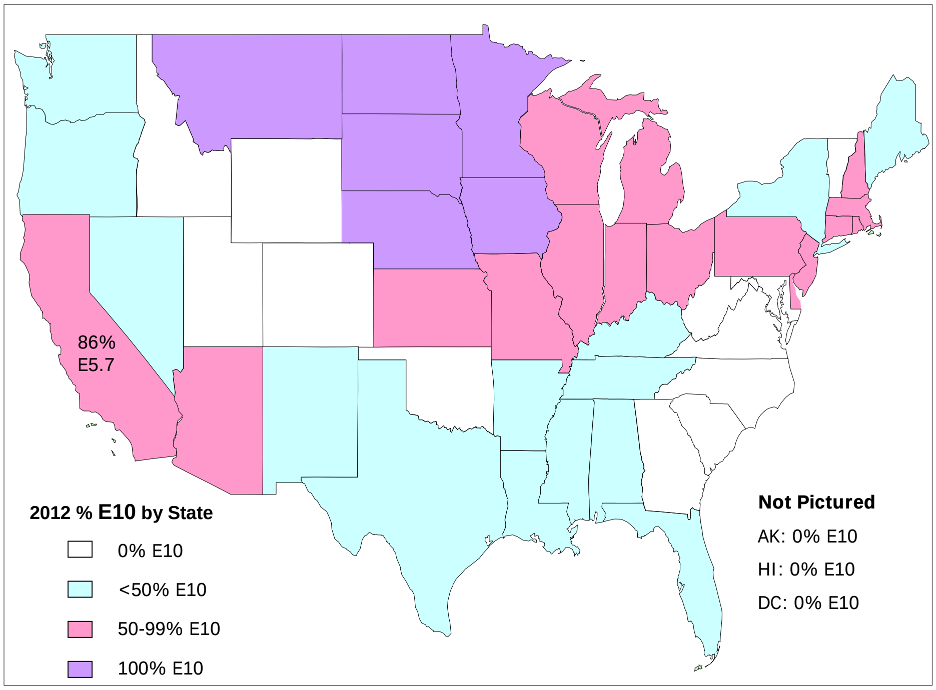
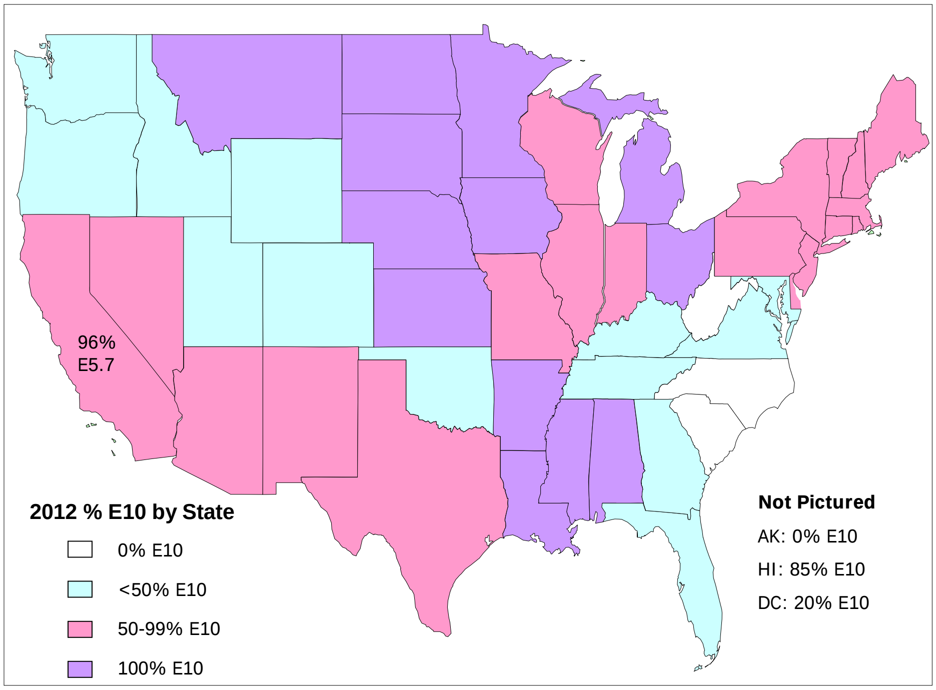


**Figure 2.2-4. 2012 Forecasted Ethanol Consumption
9.6 Bgal EIA Case, % E10 by State**



2.3 Effects of Ethanol and MTBE on Gasoline Fuel Properties

For the final rulemaking, we estimate the impact of increased ethanol use and decreased MTBE use on gasoline quality using refinery modeling conducted specifically for the RFS rulemaking.[36] The methods, analyses, and results of the refinery modeling are discussed in more detail in Chapter 7. In general, adding ethanol to gasoline reduces the aromatic content of conventional gasoline (CG) and the mid and high distillation temperatures (e.g., T50 and T90). RVP increases except in areas where ethanol blends are not provided a 1.0 RVP waiver of the applicable RVP standards in the summer. With the exception of RVP, adding MTBE directionally produces the same impacts. Thus, the effect of removing MTBE results in essentially the opposite impacts. Neither oxygenate is expected to affect sulfur levels, as refiners control sulfur independently in order to meet the Tier 2 sulfur standards.

The impacts of oxygenate use are smaller with respect to RFG. This is due to the applicability of VOC and toxics emission performance specifications, which limit the range of feasible fuel quality values. Thus, RVP and aromatic and benzene contents are not consistently affected by oxygenate type or level.

Table 2.3-1 shows the fuel quality of a typical summertime, non-oxygenated conventional gasoline and how these qualities change with the additional of 10 volume percent ethanol (10 vol%). Similarly, the table shows the fuel quality of a typical MTBE RFG blend and how fuel quality might change with either ethanol use or simply MTBE removal. Note that the table does not reflect county-specific fuel properties.

Table 2.3-1. CG and RFG Summer Fuel Quality With and Without Oxygenates

	Conventional Gasoline		Reformulated Gasoline [a]		
Fuel Parameter	Typical 9 RVP	Ethanol Blend	MTBE Blend	Ethanol Blend	Non-Oxygenated Blend
RVP (psi)	8.7	9.7	7.0	7.0	7.0
T50	218	205	179	184	175
T90	332	329	303	335	309
E200	41	50	60	58	52
E300	82	82	89	82	88
Aromatics (vol%)	32	27	20	20	20
Olefins (vol%)	7.7	7.7	4	14	15
Oxygen (wt%)	0	3.5	2.1	3.5	0
Benzene (vol%)	1.0	1.0	0.74	0.70	0.72

[a] MTBE blend –Reference Case PADD 1 South, Ethanol blend – RFS Case PADD 1 North, Non-oxy blend – RFS Case PADD 1 South

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[36] Refinery modeling performed in support of the original RFG rulemaking is also used to help separate the effects of the two oxygenates.

2.3.1 Effect of Ethanol on Conventional Gasoline Fuel Properties

To estimate effects of ethanol on conventional gasoline, we used the refinery model output shown below in Table 2.3-2. These values represent average properties across the five PADDs and winter and summer seasons.

Table 2.3-2. Properties of Conventional Gasoline Per Refinery Modeling

Case	Aromatics (vol%)	Olefins (vol%)	E200 (vol%)	E300 (vol%)	T50 (°F)	T90 (°F)	MTBE (vol%)	Ethanol (vol%)
2012 Reference	29.18	12.39	49.96	81.64	190.3	335.3	0.65	1.66
2012 RFS	29.02	12.12	51.89	83.68	187.4	326.2	0.00	3.87
2012 EIA	27.97	12.39	53.04	82.20	185.9	332.8	0.00	5.38

Using this output, we estimated an average change in each fuel property per vol% change in ethanol content. To derive these estimations, we first adjusted the Reference case properties to isolate the effects of ethanol by mathematically removing the effects of MTBE using factors derived from the RFG RIA[xliv]. Then, we calculated the change in each fuel property per change in ethanol vol% for each combination of cases. That is, we compared Reference Case to RFS Case, Reference to EIA, and EIA to RFS. Finally, we averaged the three results from the case-to-case comparisons to derive a useful factor for adjusting county-level fuel properties for a change in county-level ethanol content. These ethanol effects are shown below in Table 2.3-3.

Table 2.3-3. Change in Conventional Gasoline Properties Per Vol% Increase in Ethanol

Aromatics (vol%)	Olefins (vol%)	E200 (vol%)	E300 (vol%)	T50 (°F)	T90 (°F)
-0.46	0.02	0.91	0.06	-1.33	-0.28

2.3.2 Effects of MTBE on Conventional Gasoline Fuel Properties

In support of the final rule implementing the RFG program in 1993, refinery modeling was performed which estimated the impact of MTBE blending on the various gasoline properties.[xlv] While this modeling was performed in the context of projecting the cost of producing RFG, it is applicable to the use of MTBE in CG, as well. The refinery modeling examined a number of incremental steps involved in the production of RFG. Because RFG was mandated to contain oxygen and MTBE was expected to be the oxygenate of choice, MTBE was added in the first step of the analysis, before the fuel met the rest of the RFG requirements. Table 2.3-4 shows the results of adding MTBE based on this refinery modeling.

This modeling of MTBE effects is somewhat dated (circa 1993). However, since removing MTBE does not involve any predictions of its total usage level nor the location of its use, economics (such as crude oil price) are not a factor. It is primarily an issue of chemical properties and general refinery operation, such as octane management. Also, MTBE is always match-blended, since gasoline can be shipped with MTBE through pipelines. Thus, MTBE is always added at the refinery, allowing the refiner to take full advantage of its properties.

Table 2.3-4. Effect of MTBE on Gasoline Properties: RFG Final Rule

Fuel Parameter	Base 9 RVP Gasoline	MTBE Blend	Difference
RVP (psi)	8.7	8.7	0
T50[a]	218	207	-11
T90[a]	329	321	-8
E200 (vol%)	41	46.7	5.7
E300 (vol%)	83	84.9	1.9
Aromatics (vol%)	32.0	25.5	-6.5
Olefins (vol%)	13.1	13.1	0
Oxygen (wt%)	0	2.1	2.1
Benzene (vol%)	1.53	0.95	-0.58

[a] Estimated using correlations developed in support of EPA RFG final rule, Docket A-92-12, February 1994.

T50 = 302 – E200 / 0.49 and T90 = 707 - E300 / 0.22

As with ethanol blending, MTBE blending reduces aromatic content significantly as refiners take advantage of MTBE's high octane level. Like ethanol, MTBE also tends to increase E200 and E200 and decrease T50 and T90. Unlike ethanol, MTBE does not increase RVP.

MTBE blending is shown to modestly reduce sulfur and benzene levels, as well. This refinery modeling was performed prior to the development of the Tier 2 sulfur standards for gasoline. With these standards, gasoline must meet a 30 ppm sulfur standard on average with or without MTBE blending. As refiners can adjust the severity of their hydrotreating processes to account for various changes in feedstocks and oxygenate use, we do not expect that the removal of MTBE will result in any increase in sulfur content. Otherwise, the reversal of the differences shown in Table 2.3-4 are expected to occur when MTBE is removed from gasoline (when the MTBE content was 11 vol%).

2.3.3 Effects of Ethanol and MTBE on Reformulated Gasoline Fuel Properties

RFG has historically contained oxygenate due to the applicable 2.0 weight percent oxygen content requirement. RFG has contained 11 vol% MTBE or ten vol% ethanol, except in California, where 6 vol% ethanol blends have been common. As discussed in Section 2.2, the use of MTBE in RFG has ceased. It has been replaced by either 10 vol% or ethanol or high octane hydrocarbon blending components, such as alkylate or reformate. In either case, as discussed in Section 2.3.2, RFG will continue to have to meet stringent VOC, NOx, and toxic emission performance standards, though compliance with the NOx standard is essentially assured with compliance with the Tier 2 sulfur standards applicable to all gasoline[37].

For the NPRM, we assumed that the properties of RFG other than oxygenate would not be affected by changes in oxygenate use. For the FRM, we are utilizing the recent refinery modeling to estimate RFG properties by PADD and season for the three ethanol use scenarios.

As described above, five refinery models were developed, each representing one PADD. These models produced fuel for use in its own PADD, as well as for use in other PADDs in the several cases of PADD-to-PADD distribution of gasoline. For RFG, refinery modeling projected that a significant volume of RFG used in PADD 1 would be produced by PADD 3 refineries. Because this PADD 3 RFG is shipped to PADD 1 via pipeline, this fuel tends to be used in the southernmost RFG areas of PADD 1, namely those in Virginia, the District of Columbia and Maryland. In order to reflect this, we assumed that the RFG produced in PADD 3 will be used preferentially in the RFG areas of these three states and the RFG produced in PADD 1 will be used to fulfill the remaining demand for RFG in PADD 1. For refinery modeling, it was estimated that a small volume of RFG would be produced in PADD 3 and shipped to PADD 2. Because of the small volume involved, we did not assign this volume to a specific RFG area within PADD 2.

As part of their work, the refinery modeling contractors calibrated their model to match EPA's estimate of fuel quality existing in 2004 (i.e., the base case in this analysis). Therefore, estimates of the properties of RFG for the base case comprise an accurate estimate of actual 2004 RFG, at least on a PADD-average basis. We also have available the results of the RFG fuel survey for each RFG area. This survey data sometimes reflects significant differences in the properties of RFG for specific RFG areas within a PADD. Good examples of this would be RFG areas in New York and Connecticut, which implemented MTBE bans starting in 2004. We considered using the more precise RFG survey data to represent RFG fuel quality in the base case, but rejected this approach for two reasons. One, this would introduce an extraneous difference in RFG fuel quality between the base case and the RFS/EIA cases. While refinery model base case projections reasonably match EPA's estimate of 2004 fuel quality, they do not match exactly. Comparisons between the base case and the RFS and EIA cases would therefore include the difference between the RFG survey data and the refinery modeling contractor's estimate of this data, plus the effect of additional ethanol use and reduced MTBE use. Two, we primarily present the emission impacts of the RFS rule on a nationwide basis. On a nationwide basis, reflecting differences between RFG fuel quality within a PADD would have little impact. Also, the Ozone RSM can only reflect a single change in VOC and NOx emissions in non-attainment areas (e.g., RFG areas). Thus, differences between specific RFG areas would be eliminated by the limitation that only

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[37] Though the MSAT2 final rulemaking (72 FR 8428, February 26, 2007) eliminates these air toxics and NOx requirements beginning in 2011.

the average emission effect can be modeled. Thus, we used refinery modeling projections of RFG fuel quality for all three fuel scenarios.

Tables 2.3-5, 2.3-6, and 2.3-7 present the fuel properties of summertime RFG under the base, RFS and EIA fuel scenarios, respectively. Under the RFS and EIA cases, there is no MTBE or TAME in the fuel, so these rows are not shown (i.e., total oxygen content is the same as ethanol content in terms of weight percent).

Table 2.3-5. RFG Fuel Properties: Base Case – Summer

	PADD 1 South	PADD 1 North	PADD 2	PADD 3	PADD 5	All U.S.
RVP	7.0	7.1	7.0	7.0	6.8	6.9
Sulfur ppm	6.7	22.6	4.5	6.9	10.0	13.0
Aromatics	21.0	23.9	21.6	20.0	22.0	22.3
Benzene	0.74	0.70	0.76	0.70	0.57	0.71
Olefins	4.3	13.7	8.0	4.4	5.7	8.5
E200	59.9	55.0	58.4	59.8	54.6	56.3
E300	88.9	80.3	86.0	88.9	86.2	84.7
T50	179.2	189.6	182.5	179.8	190.5	186.9
T90	302.7	341.7	316.0	302.7	315.0	321.9
Oxygen (wt%)	2.1	2.3	2.3	2.1	1.9	2.1
MTBE (wt%O)	1.9	0.5	1.3	1.9	0.0	0.7
TAME (wt%O)	0.2	0.0	0.1	0.2	0.0	0.1
Ethanol (wt%O)	0.0	1.8	0.9	0.1	1.9	1.3

Table 2.3-6. RFG Fuel Properties: RFS Case – Summer

	PADD 1 South	PADD 1 North	PADD 2	PADD 3	PADD 5	All U.S.
RVP	7.0	7.0	7.1	7.0	6.8	6.9
Sulfur ppm	20.5	7.6	21.3	19.8	9.0	13.6
Aromatics	20.1	20.0	17.9	20.0	22.5	20.5
Benzene	0.72	0.70	0.67	0.70	0.57	0.66
Olefins	14.6	13.6	17.3	14.1	5.7	11.9
E200	52.0	57.6	54.1	52.0	54.5	54.5
E300	87.5	81.9	81.8	87.5	86.2	84.9
T50	174.7	184.2	185.3	195.7	190.5	185.9
T90	308.8	334.6	334.8	308.8	315.0	321.0
Ethanol (wt%O)	0.0	3.7	0.6	0.2	1.8	1.6

Table 2.3-7. RFG Fuel Properties: EIA Case – Summer

	PADD 1 South	PADD 1 North	PADD 2	PADD 3	PADD 5	All U.S.
RVP	7.0	7.0	7.1	7.0	6.8	6.9
Sulfur ppm	23.1	10.0	19.3	22.3	8.9	14.9
Aromatics	20.2	19.7	17.9	20.0	22.6	20.5
Benzene	0.70	0.74	0.60	0.67	0.57	0.65
Olefins	18.9	10.3	14.7	18.3	5.7	12.1
E200	52.0	57.7	55.8	52.0	54.6	54.7
E300	84.3	81.8	80.9	84.3	86.2	83.8
T50	179.4	184.0	183.4	195.7	190.5	186.4
T90	323.6	334.7	339.2	323.6	315.0	325.7
Ethanol (wt%O)	0.0	3.7	1.8	0.2	1.9	1.8

As shown in Tables 2.3-6 and 2.3-7, summer RFG produced in PADD 1 under the two increased ethanol use cases contains 10 vol% ethanol (i.e., 3.7 wt% oxygen). However, RFG produced in the other PADDs contains less than the maximum 10 vol% ethanol. For other parameters the results generally support the proposed assumption that they would remain constant, although there were some small changes. The biggest changes in the RFS and EIA fuel scenarios include higher levels of olefins, T50 and T90 and lower aromatic levels.

Tables 2.3-8, 2.3-9, and 2.3-10 present the fuel properties of wintertime RFG under the base, RFS and EIA fuel scenarios, respectively.

Table 2.3-8. RFG Fuel Properties: Base Case – Winter

	PADD 1 South	PADD 1 North	PADD 2	PADD 3	PADD 5	All U.S.
RVP	11.2	12.9	12.8	11.2	11.5	12.0
Sulfur ppm	28.0	25.5	26.2	26.9	9.5	21.1
Aromatics	21.1	19.0	13.9	20.0	20.8	19.3
Benzene	0.74	0.70	0.64	0.70	0.47	0.63
Olefins	12.6	16.0	11.6	12.2	5.7	11.1
E200	63.6	57.4	66.9	63.1	59.3	61.0
E300	88.9	80.3	79.5	88.9	86.2	84.5
T50	179.2	184.7	165.4	173.1	180.8	178.5
T90	302.7	341.7	345.2	302.7	315.0	322.7
Oxygen (wt%)	2.1	2.5	3.3	2.1	2.2	2.4
MTBE (wt%O)	2.1	0.5	0.0	2.0	0.0	0.7
TAME (wt%O)	0.0	0.0	0.0	0.1	0.0	0.0
Ethanol (wt%O)	0.0	2.0	3.3	0.1	2.2	1.7

Table 2.3-9. RFG Fuel Properties: RFS Case – Winter

	PADD 1 South	PADD 1 North	PADD 2	PADD 3	PADD 5	All U.S.
RVP	11.8	13.1	13.0	11.8	11.5	12.3
Sulfur ppm	28.0	25.0	25.4	26.7	9.4	20.8
Aromatics	21.4	19.0	17.8	21.2	23.7	20.9
Benzene	0.75	0.70	0.89	0.73	0.43	0.65
Olefins	13.3	16.0	12.3	12.6	5.7	11.4
E200	53.5	63.1	63.9	53.4	58.2	59.0
E300	87.5	81.9	79.5	87.5	86.2	84.5
T50	174.7	173.0	171.4	192.9	183.0	178.4
T90	308.8	334.6	345.2	308.8	315.0	322.7
Ethanol (wt%O)	0.0	3.7	3.0	0.0	1.8	2.0

Table 2.3-10. RFG Fuel Properties: EIA Case – Winter

	PADD 1 South	PADD 1 North	PADD 2	PADD 3	PADD 5	All U.S.
RVP	11.9	12.8	12.9	11.9	11.5	12.2
Sulfur ppm	27.5	25.2	23.8	25.6	8.5	19.9
Aromatics	22.2	19.0	20.7	21.7	23.7	21.2
Benzene	0.61	0.70	0.95	0.58	0.43	0.63
Olefins	14.8	16.0	12.3	13.6	5.7	11.9
E200	52.5	63.6	64.5	52.4	59.4	60.4
E300	84.3	81.9	79.5	84.3	86.2	83.3
T50	179.4	172.1	170.1	194.9	180.6	177.5
T90	323.6	334.3	345.2	323.6	315.0	327.9
Ethanol (wt%O)	0.0	3.7	3.7	0.0	2.2	2.6

As shown in Tables 2.3-9 and 2.3-10, winter RFG produced in PADD 1 under the two ethanol use cases contains 10 vol% ethanol (i..e., 3.7 wt% oxygen). PADD 2 winter RFG contains 10 vol% ethanol in the EIA case. However, RFG produced in the other PADDs and cases contains less than the maximum 10 vol% ethanol. On an annual average basis, RFG produced for use in California contains about 5.7 vol% ethanol (2.1 wt% oxygen). This is to be expected given the increase in NOx emissions assigned by CARB's Phase 3 Predictive Model to blends with more than 2.1 wt% oxygen. As for the summer cases, changes in other fuel parameters were small and mixed.

2.3.4 Estimation of County-Specific Gasoline Properties

In order to estimate the impact of increased ethanol use and reduced MTBE use on national emissions and air quality (described in Chapters 4 and 5), we need to estimate gasoline properties on a county-specific basis throughout the U.S. In support of previous analyses of national impacts of various rules, EPA has developed a set of gasoline specifications for each county in the U.S. for various months and calendar years.[xlvi] We based our analysis on the fuel quality specifications for January and July of 2008, since 2008 is the first year of full implementation of the Tier 2 sulfur standard of 30 ppm. Some of the EPA county-level gasoline specifications were based on old data, so we reviewed the estimates and made several modifications before applying the changes expected due to ethanol addition and MTBE removal.

First, we adjusted RVP values using more recent information on local RVP programs and to reflect commingling. Second, we revised the oxygenate content and type in each county to match the levels estimated in Section 2.2 to be sold there under each of the three ethanol use scenarios evaluated. Third, we adjusted the other properties of gasoline which are affected by the oxygenate use determined in step three. These modifications are described in more detail below.

2.3.4.1 Adjustments to RVP Levels Prior to Oxygenate Use

Our review of the NMIM database of county-specific RVP levels for July indicated that the same RVP level was often applied to all the counties of a specific state. In many cases, this appeared reasonable, since the same RVP standard applied throughout the entire state. However, in other cases, for example, Florida, most counties have a 9.0 RVP standard, while those comprising several large urban areas have a 7.8 RVP standard. The RVP levels in the NMIM database were consistent with the 7.8 RVP control programs, implying that the 7.8 RVP fuel was sold throughout the entire state. This was true for much of the south.

As mentioned above, the NMIM fuel quality database was based primarily on fuel survey data from 1999. Fuel surveys tend to focus on large urban areas, as opposed to smaller urban or rural areas. Thus, the only available fuel survey data was likely from the areas with the tighter local RVP controls. RVP control reduces gasoline supply, since lighter hydrocarbons must be removed in order to reduce RVP. Some, but not all of these hydrocarbon components can be moved to higher RVP fuel sold elsewhere. Obviously gasoline prices are now much higher than they were in 1999. So the incentive to increase supply is greater now than in 1999. As discussed in Chapter 7, high gasoline prices are projected for the foreseeable future, at least relative to those existing in 1999. Thus, we believe that it is reasonable to project that refiners will market gasoline blends with as high a level of RVP as practical given the applicable standards. For example, in Florida, two fuels will be marketed: one to meet the 7.8 RVP standard in several urban areas and another to meet the 9.0 RVP standard applicable elsewhere. There certainly could be some spillover of the 7.8 RVP fuel into adjacent 9.0 RVP counties. However, we lack data indicating the degree to which this is occurring and might occur in the future. Lacking this data, it seems more reasonable to project only that level of RVP control which is guaranteed by the applicable standards than to assume that refiners will over-comply with RVP standards and reduce the volume of gasoline which they can produce.

Past studies have shown that a typical compliance margin for RVP is about 0.3 psi. Thus, for those counties where the standard 9.0 RVP standard applies, we set the July RVP level to 8.7 psi.

EPA maintains a list of counties where its 7.8 RVP standard applies, as well as any local standards more stringent than 9.0 RVP.[xlvii] Using this list, we assigned RVP values in each county equal to 0.3 psi less than the standard applicable in July. We also reduced the RVP levels of two sets of counties which had voluntary local RVP control programs (and therefore not listed the above Guide). These two areas were Seattle and Tulsa. Based on a review of annual fuel survey data collected by the Alliance of Automobile Manufacturers (AAM)[xlviii], the fuel being sold in these areas was very similar to that for an area with a 7.8 RVP standard. Thus, we assigned a value of 7.5 psi RVP to Tulsa County, Oklahoma, and to King, Pierce, and Snohomish Counties, Washington.

We then assigned an RVP value of 6.8 psi to counties subject to the Federal RFG program, again based on an EPA list of the counties subject to this program.[xlix] The EPA list of RFG counties includes the Baton Rouge, Louisiana, area. However, litigation has held up implementation of this program, so these counties were assigned RVP values consistent with the currently applicable 7.8 RVP standard instead. The RVP value of 6.8 psi was typical for the RFG areas included in the AAM fuel surveys.

For the purposes of our analysis, we also assigned the entire State of California an RVP of 6.8 psi, since California fuel must meet a similar VOC performance standard to RFG. Likewise, RVP in Maricopa and Pinal counties in Arizona were assigned a level of 6.8 psi. These two counties are subject to Arizona's unique reformulated gasoline program. This program basically requires that gasoline sold in these two counties meet either the California RFG or Federal RFG standards. Thus, RVP in these two counties will be the same as in those other two areas, similar to national RFG fuel.

These RVP levels for 9.0 RVP and low RVP areas are appropriate when no ethanol is being blended into gasoline. However, most of these areas increase the applicable standard by 1.0 psi for ethanol blends, which is the typical impact of ethanol blending. Therefore, these levels need to be adjusted for the expected level of ethanol use, which is discussed below.

2.3.4.2 County-Specific Oxygenate Type and Content

The three ethanol use scenarios developed in Section 2.2 assign ethanol and MTBE use by state and fuel type (i.e., conventional gasoline, RFG, oxyfuel). In order to develop county level estimates of ethanol and MTBE use, we simply assume that ethanol and MTBE use within a state and fuel type is uniform. For example, if the E10 market share in conventional gasoline Iowa is 34%, then ethanol use in every county receiving conventional gasoline in Iowa was assigned an E10 market share of 34%.

As described above, we nearly always assume that ethanol use is in the form of a 10 vol% blend with gasoline. The two exceptions are California fuel and Arizona RFG.

California fuel containing ethanol is assumed to contain 5.7 vol% ethanol. Arizona RFG is assumed to be a mix of 67% California fuel and 33% Federal RFG produced in PADD 3. Therefore, its ethanol content is a 2/1 mix of the ethanol contents of California RFG and PADD 3 Federal RFG.

Similarly, we assume that MTBE is used at an 11 vol% level in RFG, since this meets the previously mandated oxygen content of 2.1 wt%. MTBE in conventional gasoline was assumed to be used at a 3 vol% level. This was somewhat arbitrary, but does not affect the outcome of the analysis. The effect of MTBE blending on emissions is very linear. Therefore, whether the fuel pool in a particular area consists of 10% of a 10 vol% MTBE blend or 33% of a 3 vol% MTBE blend is immaterial. Though MTBE is present in the 2012 Reference Case, it is assumed to be completely phased-out in the RFS and EIA ethanol use cases.

EPA's NMIM model (described in more detail in Chapter 4) will only accept a single composite fuel for each county. Therefore, we could not use the mix of fuels often projected to be supplied to counties developed in Section 2.2. In order to produce a single, composite fuel, we simply multiplied the ethanol and MTBE contents of each blend by their market share in that county in order to determine the average ethanol and MTBE contents of each county's fuel pool, respectively. For example, if the E10 market share in a specific county was 50%, the ethanol content for that fuel was set to 5 vol%. We then adjusted the other fuel properties to account for these oxygenates, which is discussed below.

2.3.4.3 Adjustments to Other Gasoline Properties for Oxygenate Use

We next adjusted other gasoline properties to account for the level of county-specific oxygenate use projected to occur under the three ethanol use scenarios. Our review of the NMIM fuel database indicated that properties, such as aromatics, reflected the level of oxygenate use existing in 1999. Therefore, we used the oxygenate levels in the NMIM database, which differ from those developed in Section 2.2 for 2004, as the basis for our adjustments of the other fuel properties. For example, if the NMIM database indicated an ethanol content of 3 vol% for fuel sold in Wayne County, Michigan, and the 2004 projection for this county was 5 vol%, we adjusted the NMIM fuel properties for this county to reflect the addition of 2 vol% ethanol.

The bases for these adjustments were those developed in Sections 2.3.1 through 2.3.4 above. As described there, these adjustments apply primarily to conventional gasoline. These adjustments are summarized in Table 2.3-11 below.

Table 2.3-11
Change in Property per 1 Vol% Increase in Ethanol and MTBE Content

	E200 (%)	E300 (%)	Aromatics (Vol%)	Olefins (Vol%)	RVP (psi)
Conventional Gasoline					
Ethanol	+1.0	+0.24	-0.5	-0.16	+0.1
MTBE	+0.52	+0.17	-0.59	0	0
Reformulated Gasoline					
Ethanol	0	0	0	0	0
MTBE	0.1	0.1	0	0	0

To calculate new fuel properties for each county, we applied the ethanol and MTBE factors to the change in county-level ethanol and MTBE content. The overall adjustment to the fuel property was the addition of the ethanol effect and the MTBE effect to the baseline fuel property.

For the impact of ethanol blending on aromatic and olefin contents, we followed a slightly different approach. We assumed that the ethanol present in 1999 had been splash-blended, while that being used in the future will be match-blended. This difference doesn't affect the adjustment of RVP, E200, or E300, since we assume that these parameters are affected in the same way regardless of whether the ethanol is splash- or match-blended. However, the change in aromatics does depend on which blending approach is used. The situation is similar for olefins, though to a lesser extent. Thus, we employed what can be thought of as a two step process in adjusting aromatic and olefin contents for the change in ethanol content between the NMIM estimate and those for the three ethanol use scenarios developed in Section 2.2.

The first step is to account for any splash-blended ethanol in the NMIM database. With splash-blending, aromatic and olefin contents are reduced simply by dilution, since ethanol contains is neither an aromatic nor an olefin. The following equation shows how the NMIM level of aromatics was adjusted:

$$\begin{matrix}\text{Intermediate}\\\text{Aromatic}\\\text{Content}\end{matrix} = \begin{matrix}\text{NMIM}\\\text{Aromatic}\\\text{Content}\end{matrix} \div \left(1 - \left(\begin{matrix}\text{NMIM}\\\text{Ethanol}\\\text{Content}\end{matrix}\right)\left(\begin{matrix}\text{NMIM}\\\text{Ethanol}\\\text{Market}\\\text{Share}\end{matrix}\right) \div 100\right)$$

Then, the effect of any ethanol projected to be sold in that county in the three ethanol use scenarios developed in Section 2.2 was applied using the approach described above for RVP, E200 and E300 (and for the effect of MTBE on aromatics and olefins). In this case, the NMIM ethanol content and market share is zero, since we already adjusted the NMIM aromatic and olefin contents to represent those existing for a zero ethanol content. For example, the equation for the ethanol effect is as follows:

$$\begin{array}{c}\text{New Fuel}\\ \text{Property}\\ \text{Level}\end{array} = \begin{array}{c}\text{Intermediate}\\ \text{Fuel Property}\\ \text{Level}\end{array} + \left(\begin{array}{c}\text{RFS}\\ \text{Ethanol}\\ \text{Content}\end{array}\right)\left(\begin{array}{c}\text{RFS}\\ \text{Market}\\ \text{Share}\end{array}\right) \times \left(\begin{array}{c}\text{Fuel Property}\\ \text{Change per 1}\\ \text{vol\% Ethanol}\\ \text{Increase}\end{array}\right)$$

We make one final adjustment to RVP to add a commingling effect to account for areas where vehicles may be fueled by a mix of ethanol-blend gasoline. Commingling of ethanol and non-ethanol blends can increase the average RVP of gasoline in vehicle fuel tanks by 0.1-0.3 psi. Appendix 2-A presents a detailed analysis of the impact of commingling on the RVP of gasoline in vehicle fuel tanks. Table 2.3-12 presents our estimate of the net impact of commingling on in-use RVP as a function of the market share of ethanol blends.

Table 2.3-12. Impact of Ethanol Blends on In-Use RVP (psi)

E10 market share	Commingling Impact
0%	0
2%	0
5%	0.116
10%	0.116
20%	0.202
30%	0.238
40%	0.264
50%	0.273
60%	0.263
70%	0.226
80%	0.172
90%	0.102
97%	0.102
100%	0.000

EPA's MOBILE6.2 model normally accounts for this effect automatically. However, when NMIM is used to run MOBILE6.2, the commingling effect in MOBILE6.2 is by-passed. Therefore, any effect of commingling needs to be accounted for in the average fuel specified to be sold in each county. To roughly account for this effect, we increased RVP by 0.1-0.27 psi in all states where the E10 market share was significant (i.e., more than 5%) but less than 95%. The states which fell into this category, for CG and RFG, are shown in Table 2.3-13. The specific RVP increase depended on the ethanol market share in that county, as indicated in Table 2.3-12.

Table 2.3-13. States Where RVP was Increased Due to Commingling

Fuel Case	**Conventional Gasoline**
Reference	ILLINOIS SOUTH DAKOTA INDIANA NEBRASKA OHIO IOWA KANSAS NORTH DAKOTA WISCONSIN ALABAMA MICHIGAN MISSOURI
RFS	ALABAMA ARIZONA ARKANSAS COLORADO FLORIDA KENTUCKY LOUISIANA MAINE MISSISSIPPI NEVADA NEW MEXICO PENNSYLVANIA TENNESSEE WASHINGTON WYOMING
EIA	COLORADO FLORIDA KENTUCKY LOUISIANA PENNSYLVANIA TENNESSEE WASHINGTON WYOMING IDAHO NEW HAMPSHIRE NEW JERSEY NEW YORK OKLAHOMA OREGON TEXAS UTAH
	Reformulated Gasoline
Reference	ARIZONA MASSACHUSETTS NEW JERSEY TEXAS
RFS	KENTUCKY PENNSYLVANIA NEW HAMPSHIRE NEW JERSEY NEW YORK TEXAS MAINE CONNECTICUT DELAWARE ILLINOIS INDIANA MASSACHUSETTS MISSOURI RHODE ISLAND VERMONT WISCONSIN
EIA	KENTUCKY PENNSYLVANIA NEW HAMPSHIRE NEW JERSEY NEW YORK TEXAS MAINE CONNECTICUT DELAWARE ILLINOIS INDIANA MASSACHUSETTS MISSOURI RHODE ISLAND VERMONT WISCONSIN

2.4 Effects of Biodiesel on Diesel Fuel Properties

Our assessment of the effects of biodiesel on diesel fuel properties is found in the 2002 EPA report "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions"[1]. Table 2.4-1 below displays the difference in fuel properties between biodiesel (B100) and conventional diesel. Note that by 2010, all highway and nonroad diesel fuel will meet a 15 ppm cap on sulfur.

The data in the table below were derived from a wide-range of biodiesels, primarily plant- and animal-based. The 2002 EPA report did not provide properties for soy-only based biodiesel.

Table 2.4-1. Comparison Between Biodiesel and Conventional Diesel Fuel[a]

	Average Biodiesel	Average Diesel
Natural cetane number	55	44
Sulfur, ppm	54	333
Nitrogen, ppm	18	114
Aromatics, vol%	0	34
T10, deg F	628	422
T50, deg F	649	505
T90, deg F	666	603
Specific gravity	0.88	0.85
Viscosity, cSt at 40 deg F	6.0	206

[a] Conventional diesel fuel sold outside of California.

Chapter 2: Appendix
Comprehensive Vehicle Refueling Model

Vehicle refueling patterns affect non-exhaust emissions in a number of ways, including the distribution of vehicle fuel tank fill levels existing at any given time and the quality of fuel in the tank. Given the interaction between these parameters, we have developed a single model which represents vehicle refueling patterns. We then use this model to estimate the distribution of vehicle fuel tank fill levels and the quality of fuel in the vehicle fuel tanks.

Vehicle fuel tank fill levels are primarily a function of the level at which people refuel their vehicles and the volume of fuel which they add. In-use, vehicle fuel tanks will slowly empty until the point of refueling again. The California Air Resources Board (CARB) recently conducted a survey of vehicle refueling patterns in three California cities. We will base our estimates of refueling patterns primarily on these data.

Most fuel parameters remain unchanged as the fuel is burned. One except is volatility, particularly RVP, which decreases due to evaporation of the fuel as the tank heats up either due to rising ambient temperatures or vehicle operation (e.g., heat transfer from the exhaust system, engine cooling air flowing under the vehicle, and fuel recirculation from the engine compartment).

While ethanol content doesn’t change significantly while the vehicle is being operated, the ethanol content of gasoline in vehicle fuel tanks can be a function of vehicle refueling patterns if some of the specific gasolines being marketed in an area contain ethanol and some do not. The effect of ethanol on RVP is not linear. Thus, knowledge of the distribution of ethanol content in vehicle fuel tanks is important in estimating the RVP of gasoline in vehicle fuel tanks and non-exhaust emissions. We use the vehicle refueling model to estimate ethanol content, fuel RVP, and average fill level.

There are four main aspects of the vehicle refueling model. The first two aspects affect all types of gasoline, ethanol containing or not. The first aspect is a description of the refueling patterns of vehicle operators. How low is the tank when they refuel? How much fuel do they add? Does the volume of fuel added depend on how low the tank was when they stopped to refuel? The second aspect is the weathering of the fuel as the vehicle is operated. In general, the degree of weathering, or RVP reduction, depends on both the ambient temperature and initial RVP of the fuel.

The third aspect of the model is the effect of ethanol on RVP. While the ethanol content of gasoline tends to be either 5.7 or 10 percent by volume (vol%) at the service station, the ethanol content of gasoline in a vehicle’s fuel tank can vary from zero to 10 vol%. The fourth aspect of the model is a description of the probability that a vehicle operator will purchase fuel at the same service station as the last refueling or at another outlet selling the same brand fuel (i.e., gasoline brand loyalty). Brand loyalty is relevant, because service stations carrying the same brand of gasoline almost always sell either gasoline with ethanol or gasoline without ethanol, but not both. It is the mixing of gasoline with and without ethanol is vehicles' fuel tanks that can cause the RVP of fuel in the tank to differ from that dispensed at the service station. This is referred to as the commingling effect.

Each of these four aspects of the vehicle refueling model is described below.

2A.1 Vehicle Refueling Patterns

During August and September, 2001, the CARB surveyed consumers' refueling habits at 19 service stations in three local areas (Lake Tahoe, the Bay Area and Los Angeles).[38] Basic refueling information was obtained for 396 vehicle refuelings (i.e., initial fuel tank level and volume of fuel added). Fuel samples were also obtained from 254 vehicles, though we are most interested in the volumetric data here. CARB also asked those refueling whether they refueled with the same brand gasoline the last time the vehicle was refueled.

We obtained and analyzed the raw volumetric fuel data obtained by CARB. Of the 396 sets of data, 391 included both initial fuel tank level and volume of fuel added. One of the two pieces of information was missing for five vehicles, so we discarded these partial data sets from the analysis. The tank fill level prior to refueling was recorded in terms of eighths of a fraction of a full tank, as this is usually how the tank fill level is indicated on the vehicle dash board. Table 2A-1 shows the probability of a vehicle being refueled at various fuel tank fill levels.

Table 2A-1. Fill Level Prior to Refueling

Fraction of fill level	Probability
0.000	0.414
0.125	0.133
0.250	0.253
0.375	0.054
0.500	0.095
0.625	0.020
0.750	0.020
0.875	0.010

As can be seen, over 40% of the vehicles surveyed came in with an "empty" tank.

CARB also recorded whether the vehicle operator "filled up" the tank or not. We observed that there was a trend towards a greater probability of a "fill up" as the level of the tank prior to refueling increased. Table 2A-2 shows the probability of a fill-up as a function of tank fill level prior to refueling.

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[38] "Draft Assessment of the Real-World Impacts of Commingling California Phase 3 Reformulated Gasoline, California Environmental Protection Agency, Air Resources Board, August 2003.

Table 2A-2. Probability of Fill-Up as a Function of Initial Tank Fill Level

Initial Tank Fill Level	Likelihood of a Fill-up
0.000	0.117
0.125	0.500
0.250	0.586
0.375	0.619
0.500	0.784
0.625	0.875
0.750	0.750
0.875	0.750

Overall, when the tank was at least half full, the tank was filled up 79% of the time.

In those cases where the fuel tank was not filled to capacity, the volume of fuel added was recorded in terms of gallons. Therefore, some processing was required to estimate the final fill level in terms of fraction of tank capacity. To do so, we had to estimate the volume of each vehicle's fuel tank. CARB recorded the basic model type of each vehicle in the survey. Based on this model type, we placed each vehicle into one of six possible categories. First, each vehicle was identified as either a car or light truck. Then, we estimated whether it would have a relatively small, medium, or large fuel tank for that vehicle class. The fuel tank sizes assumed for each class are shown in Table 2A-3 below.

Table 2A-3. Estimated Fuel Tank Volumes (gallons)

Relative Size	Car	Light Truck
Small	12	16
Medium	16	20
Large	20	24

Using these tank volumes, we converted the volume of fuel added during partial fill ups to an equivalent fraction of tank volume and added this to the observed initial fill level to estimate the final fill level. In five cases (out of the 176 partial fills), the estimated final fill level exceeded 100%. Either the initial gauge reading was off or rounded up, or more likely, our estimate of the total tank volume was too small. In these cases, we reduced the final fill level to 95%. (Given that this was a partial fill-up, the final fuel tank level had to be less than 100%.)

For all of the partial fill-ups, we converted the volume of fuel added from gallons of fuel to fractional tank volume. Both the mean and standard deviation of these volumes were determined as a function of initial fill level. These figures are shown in Table 2A-4.

Table 2A-4. Volume of Fuel Added During Partial Fills (% of Fill Level)

Initial Fill Level	Volume of Fuel Added	
	Mean	Standard Deviation
0.000	0.406	0.200
0.125	0.434	0.157

0.250	0.382	0.167
0.375	0.451	0.185
0.500	0.314	0.120
0.625	0.325	---
0.750	0.225	0.04
0.875	0.030	---

As can be seen from Table 2A-4, the final fill level from partial fills is very close to a full tank when the initial fuel tank level was 0.625 or higher. The actual number of cases when vehicles initiated refueling when the tank fill level was 0.625 or higher was quite small (20). The number of partial fills surveyed was even smaller (4). Given this small number and the fact that the fraction of fill-ups for half full tanks exceeded that found for 0.75 and 0.875 full tanks (from Table 2A-3), we assumed that all tanks which were at least half full when refueling was initiated were filled-up. When the initial fill level was less than 0.5, we assumed that the mean volume of fuel added were those shown in Table 2A-4.

As also can be seen from the figures in Table 2A-4, the estimates of the standard deviation in the volume of fuel added are substantial relative to the mean volumes of fuel added. We desired to reflect this variability in the volume of fuel added during partial fills. Thus, we utilized both the estimates of the mean and standard deviation in the volume of fuel during refueling. We accomplished this by multiplying the standard deviation by a randomly generated standard normal deviate and adding this to the mean volume of fuel added to estimate the volume of fuel added during each partial refueling.

2A.2 Weathering

Fuel weathering is the result of the evaporation of the lighter components of gasoline when the temperature in the fuel tank rises. This temperature rise can be the result of diurnal swings in ambient temperature or from vehicle operation. In the latter case, the heat can be transferred either convectively from the exhaust system and engine cooling air flowing under the vehicle or conductively from recirculated fuel from the engine's fuel system or both. Gasoline is a mixture of many different chemicals. Some of these chemicals, such as butane, evaporate more quickly than other chemicals with a higher molecular weight, such as octane. The loss of lighter chemicals can be sufficient to reduce the concentration of these lighter chemicals in the liquid gasoline. This reduces the RVP of the fuel and its tendency to evaporate as the current tank of fuel is consumed.

We base our estimate of weathering on RVP on the methodology currently in MOBILE6.2. This estimate was first developed for MOBILE4 and was also used in MOBILE5. This methodology first calculates an effective in-use tank temperature (T_{evap}) which drives fuel evaporation. This temperature is a function of the daily minimum temperature (T_{min}) and maximum temperature (T_{max}), as indicated in the following equation:

$$T_{evap} = -1.7474 + 1.029 * T_{min} + 0.99202 * (T_{max} - T_{min}) - 0.0025173 * T_{min} * (T_{max} - T_{min})$$

The loss in RVP is a function of both T_{evap} and dispensed RVP, as indicated by the following equation:

$$\text{RVP reduction (psi) due to weathering} = -2.4908 + 0.026196 * T_{evap} + 0.00076898 * T_{evap} * \text{Dispensed Fuel RVP}$$

This RVP loss is that occurring when the vehicle fuel tank is 54.57% full, which is the effective in-use average tank level for estimating non-exhaust emissions in MOBILE6.2. For a typical high ozone day where the ambient temperature might range from 72 F to 96 F, and for a dispensed RVP of 9 psi, the RVP loss due to weathering is 0.54 psi. In order to estimate weathering at other tank fill levels, we assume that weathering is linear with tank fill level.

2A.3 Effect of ethanol on RVP as a Function of Ethanol Content

In general, the chemicals comprising gasoline blend ideally. That is, the property of the finished gasoline is the sum of the property of each component weighted by its molar, volume or mass fraction, whichever is technically appropriate. Each component of gasoline has its own RVP level. Adding a component to gasoline at the level of 10 volume percent (vol%), which is the typical ethanol concentration would increase the blend's RVP by 10% of the component's RVP and decrease the blend's RVP by 10% of the original RVP. For example, normal butane with an RVP of 42 psi can be added to gasoline with an RVP of 8 psi. If the butane is added to a final level of 5 vol%, then the final RVP is 0.05 times 42 plus 0.95 times 8, or 9.7 psi.

Ethanol blending affects the RVP of the finished gasoline quite differently. Ethanol is a highly polar compound, due to the presence of the hydroxyl radical. In pure liquid ethanol, these hydroxyl radicals interact with each other, increasing the degree of attraction between ethanol molecules and lowering their tendency to evaporate. This phenomena is commonly known as hydrogen bonding and is most commonly associated with water. When added to non-polar hydrocarbons at low concentrations, such as those comprising gasoline, the evaporative tendency of ethanol increases dramatically. This increase in vapor pressure is indicated by what is referred to as the activity coefficient. The activity coefficient is the ratio of a compound's actual vapor pressure in a mixture to that predicted by ideal blending. Table 2A-5 shows ethanol's activity coefficient at various levels of concentration in a typical gasoline.

Table 2A-5. Activity Coefficient of Ethanol in Gasoline Blends [39]

Ethanol Concentration (vol%) *	Activity Coefficient
3%	7.5-8.0

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[39] Harley, Robert A. and Shannon C. Coulter-Burke, "Relating Liquid Fuel and Headspace Vapor Composition for California Reformulated Gasoline Samples Containing Ethanol," Environmental Science and Technology, Volume 34, Number 19, 2000. pp 4088+4094, Figure 3. It should be noted that the ethanol concentrations shown in the reference are in terms of mole fraction, which are essentially a factor of 2 higher than volume fraction.

6%	3.8-4.1
10%	2.3-2.5
14%	1.9-2.0
18%	1.6-1.8

As can be seen, these activity coefficients are substantially greater than 1.0, indicating a significant increase in the vapor pressure of ethanol beyond that predicted by ideal blending.

Adding ethanol to gasoline can also increase the vapor pressure of the hydrocarbon components. In general, instead of the hydrocarbons' vapor pressures decreasing with the addition of another component (e.g., by 10% with the addition of 10 vol% ethanol), they remain constant or even increase. This could be due to a tendency of the hydrocarbons in the vapor phase to "bounce" off of the ethanol molecules at the surface of the liquid phase.

A number of studies have shown that the full effect of ethanol's impact on RVP is reached at very low concentrations. For example, a study performed by the Energy and Environmental Research Center at the University of North Dakota indicates that 90% of the full impact of ethanol on RVP is reached when the ethanol concentration is only 2 vol%.[40] Researchers at the University of Delaware found the same relationship.[41] Below 2 vol% ethanol, we have assumed that the effect is essentially linear.

The full effect of ethanol on gasoline RVP is a function of the RVP of the base hydrocarbon gasoline. In general, the increase in RVP caused by ethanol blending increases as the base RVP decreases. The actual RVP of specific commercial ethanol and non-ethanol gasoline blends are generally known for a specific area being modeled. Thus, they are not a primary concern here. However, in order to develop realistic estimates of weathering and commingling across a range of ethanol blend market shares, it would be helpful to use realistic RVP levels for commercial ethanol and non-ethanol gasoline blends.

Ethanol blending generally occurs under two types of RVP standards. One type of standard requires that both ethanol and non-ethanol blends meet the same RVP standard. This is the case in reformulated gasoline (RFG) areas. In most other areas, ethanol blends are allowed to meet an RVP standard 1.0 psi higher than that applicable to non-ethanol blends.

We will estimate the impact of weathering and commingling for both situations. For RFG-like situations, we will assume that both ethanol and non-ethanol blends have

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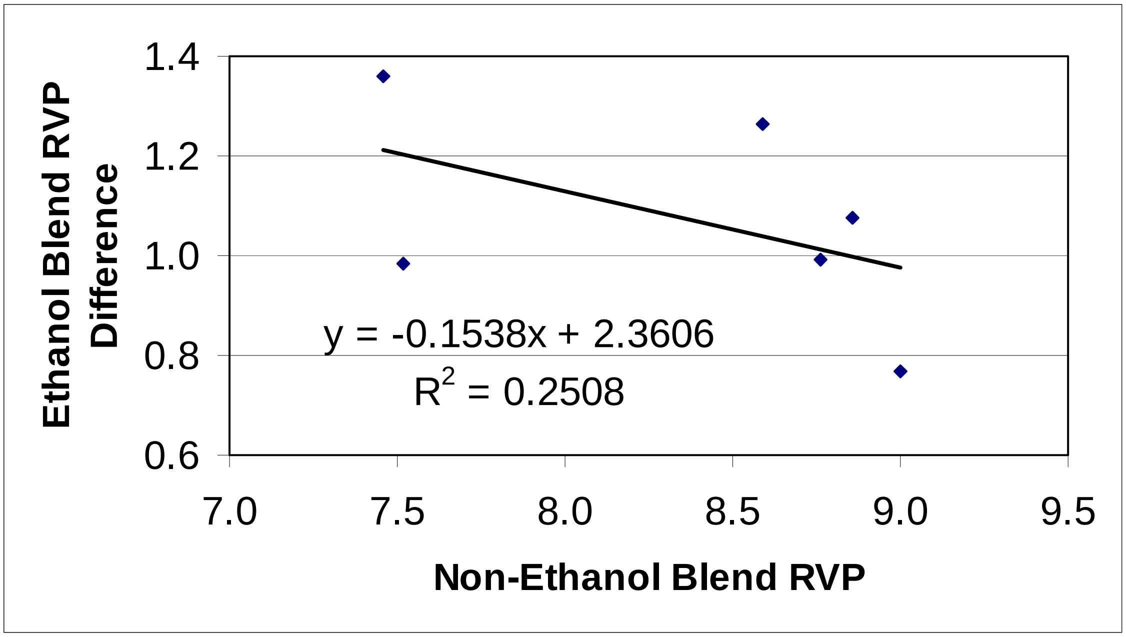
[40] Aulich, Ted and John Richter, "Addition of Nonethanol Gasoline to E10 – Effect on Volatility," Energy and Environmental Research Center at the University of North Dakota, July 15, 1999.

[41] Bennett, Alison, Stephan Lamm, Hasan Orbey and Stanley I. Sandler, "Vapor-Liquid Equilibria of Hydrocarbons and Fuel Oxygenates. 2," Jounal of Chemical Engineering Data, Volume 38, 1993, pp. 263-269, Figure 7. This reference shows the ethanol concentration in terms of mass fraction, which is nearly identical to volume fraction.

the same RVP. In order to estimate the impact of ethanol blending in areas where ethanol blends are allowed to have a higher RVP level, we evaluated recent fuel quality data collected by the Alliance of Automobile Manufacturers. We combined the data collected from 2001-2003 and found six cities where significant numbers of both ethanol and non-ethanol blends were sampled and analyzed. These six cities were: Albuquerque, Cleveland, Denver, Detroit, Minneapolis, and Seattle. The average RVP levels of the non-ethanol gasoline samples in each city ranged from 7.46-9.00 psi, while that of the ethanol blends ranged from 8.50-9.93 psi. We observed a relationship between the RVP of the non-ethanol gasolines and the difference between the RVP of the ethanol and non-ethanol blends. In general, as the RVP of the non-ethanol gasoline increased, the difference between the RVP of the ethanol and non-ethanol blends decreased. Figure 2A-1 shows this relationship for the six cities, along with a best-fit line based on least squares regression. The r-squared value for the best-fit line was 0.25.

Figure 2A-1. Effect of Ethanol Blending on RVP in Six U.S. Cities



On average, ethanol blending led to a 1.0 psi RVP higher RVP level when the RVP level of the non-ethanol gasoline was 9.0 psi. Ethanol's effect increased to 1.2 psi when the RVP level of the non-ethanol gasoline was 7.5 psi. When evaluating the effect of weathering and commingling, we will evaluate non-ethanol gasoline RVP levels of 6.8, 7.8 and 9.0 psi, as these are common RVP standards in use today. Using the relationship indicated in Figure 1, the RVP levels of the ethanol blends associated with these base RVP levels are 8.1, 9.0, and 10.0 psi, respectively.

2A.4 Brand Loyalty

CARB recently conducted a fairly extensive direct survey of vehicle refueling patterns. This study is both more recent and more extensive than those made in the past.[li] During their refueling survey, CARB asked vehicle operators whether the vehicle was refueled with the same brand of fuel the previous time the vehicle was refueled. The resulting responses are summarized in Table 2A-6 below.

Table 2A-6. Brand Loyalty in the CARB Refueling Survey

Response to Question: Did you refuel with the	Los Angeles	Bay Area	Lake Tahoe
"Yes"	62%	59%	31%
"No"	31%	38%	67%
"Don't Know"	7%	3%	2%
Breakdown of Retail Outlets Surveyed			
Major Brands (Shell, Chevron, Texaco, Mobil, ARCO)	4 (100%)	5 (84%)	3 (33%)
Intermediate (Valero)	0 (0%)	1 (16%)	0 (0%)
Local Brands (USA, Fox, United)	0 (0%)	0 (0%)	6 (67%)

CARB thought that the relatively low level of brand loyalty in Lake Tahoe was due to a high rate of rental car usage in that city. However, they did not present any data regarding the fraction of total VMT by rental vehicles to justify their rationale. Rental vehicle VMT would have to represent roughly half of all VMT in the Tahoe area (assuming such use was negligible in the other two areas) for this factor to explain the large difference seen in Table 2A-6. This seems quite unlikely, despite Lake Tahoe being a resort area.

We believe that there is a more likely explanation for the difference. A review of the service stations surveyed in the three areas shows significant differences in the types of brands surveyed. The service stations surveyed in Los Angeles and the Bay Area were dominated by major, nationally recognized brands. Those in Lake Tahoe were dominated by more local brands. We believe that brand loyalty could easily be stronger for nationally known brands which advertise and which offer their own credit cards. A few major brands offer a significant discount when their credit card is used to buy their gasoline (e.g., Shell, BP).

The breakdown of service stations into major and local brands in the three areas is shown in the lower half of Table 2A-6. We have defined major brands to include vertically integrated oil companies which have been in the retail business for several decades, market in several regions across the U.S. and are known to widely advertise. As shown in Table 2A-6, all four retail fuel outlets surveyed in Los Angeles fell into this category, while five out of six stations in the Bay Area reflected major brands. The sixth outlet in the Bay Area was a Valero outlet. Valero is a newcomer in the retail market relative to Chevron, Shell, etc. However, it is currently the largest refiner in the U.S. and offers its own credit card. Thus, Valero appears to fall into an intermediate category somewhere between the major brands and the local brands.

The situation is essentially reversed in Lake Tahoe. Two-thirds of the retail outlets surveyed were local brands. Only three out of nine outlets represented major brands.

In order to investigate the potential difference between brand loyalty between major and non-major brands, we assumed that each type of fuel brand had its own level of loyalty across the three areas. We then estimated these two levels of brand loyalty identified to best predict the overall brand loyalty in each area. Overall, loyalty levels of 62% for major brands and 15% for non-major brands (including Valero) fit the survey data reasonably well.

The U.S. Energy Information Administration (EIA) tracks a broad range of proprietary physical and financial data from large energy producers through their Financial Reporting System. This information includes the volume of gasoline sold through retail outlets owned by or leased from these companies and selling fuel with the company's brand name. Up to 1997, these retail outlets sold about 45% of all gasoline sold in the U.S. In 1998, EIA expanded the number of companies included in the Financial Reporting System by 50% (from 22 to 33 companies). The percentage of gasoline sold by these firms' retail outlets increased to 62% of all gasoline sold in the U.S.

The nature of the firms included in the Financial Reporting System changed with the eleven companies added in 1998. Prior to 1998, this system included 22 companies. A few of these firms were not oil companies, (e.g., Burlington Resources, Enron, Sonat/El Paso Energy, Union Pacific Resources, USX). Several others were not major gasoline retailers, at least under their corporate names (e.g., Anadarko Petroleum, Kerr-McGee, Occidental Petroleum).

In 1998, EIA added an additional 11 companies to the Financial Reporting System. Most of these were gasoline refiners (e.g., Citgo, Clark, Equilon, Lyondell-Citgo, Motiva, Sunoco, Tesoro, Ultramar Diamond Shamrock (UDS), Valero and Williams). At the same time, the volume of gasoline sold by the original 22 companies decreased to 31% of all gasoline sold in the U.S. This drop is likely due to the spin-off of refineries by companies like Shell and Texaco to partnerships like Motiva and Equilon. The actual retailing of this 14% of gasoline sales likely didn't change significantly (e.g., the retail brand name continued to be Shell). The net increase of 17% of U.S. gasoline sales represented the other refiners, such as Tesoro, Valero, Citgo, USD, etc. These latter companies have a much more regional footprint and have not established brand name familiarity coupled with a perception of higher quality gasoline. With the exception of the single Valero outlet in the Bay Area, none of the stations surveyed by CARB offered gasoline from these companies. Thus, we believe that the major brands included in the CARB survey are more similar to the fuel suppliers included in EIA's Financial Reporting System prior to 1998 than to those included after 1998.

Given this, we estimate that 45% of U.S. gasoline sales are sold through stations carrying a major brand. Weighting the loyalty levels of 62% for major brands by 45% and the loyalty level of 15% for other brands by 55% yields an overall national average loyalty level of 36%. For non-loyal consumers, the probability of brand selection is assumed to be random. Practically, this means that the probability of choosing either a non-ethanol or ethanol blend depends on each fuel's market share.

The exact question asked by the CARB surveyors was whether the vehicle had been refueled the last time with the same brand of fuel. CARB assumed that this meant that the vehicle was always refueled with the same brand. However, the question was limited to only the refueling immediately preceding the current one. Our primary estimate of brand loyalty is that directly addressed by the CARB survey: the likelihood that the previous refueling was with the same brand of gasoline. We also estimate the sensitivity of our estimate of commingling to the assumption made by CARB below.

2A.5 Procedures for Modeling Vehicle Refueling and Resultant Fuel Quality

We developed a model to predict the fuel tank level and fuel quality existing in a typical onroad vehicle through 500 refuelings. The vehicle is assumed to begin its life with a full tank of non-ethanol fuel. The fuel tank level at which the vehicle is refueled is based on the probabilities shown in Table 2A-1 above. First, a cumulative distribution of refueling probabilities was generated by adding the probabilities shown in the second column of Table 2A-1. Then, a random number valued between 0.0 and 1.0 is generated. If the random number is less than the cumulative probability of the tank being empty at refueling (0.414), the tank is assumed to be empty. If the random number is between this figure and the cumulative probability of the tank being 1/8 full at refueling (0.547), the tank is assumed to be 1/8 full at refueling, etc.

The RVP level of this fuel is reduced using the weathering equation shown in Section 2A.2. The level of RVP loss is assumed to be proportional to the volume of fuel used since the last refueling. For example, a vehicle might be driven from a full fuel tank down to a tank which is 20% full. Fuel usage is 80% of a tank. The above RVP weathering equation represents the RVP drop for a vehicle being driven from a full tank down to a 60% full tank, or a fuel usage of 40%. Therefore, the RVP decrease due to weathering in this case would be twice that indicated by the weathering equation in Section 2A.2. Fuel composition (i.e., ethanol content) is assumed to be unaffected by driving.

Only the hydrocarbon portion of the fuel is weathered, since the effect of ethanol on RVP is essentially independent of its concentration. Thus, the value of RVP used in the weathering equation is that for the hydrocarbon portion of the fuel, not the total RVP of the blend. This means that we need to track the RVP of the hydrocarbon portion of the fuel separately.

The probability of the fuel tank being completely filled during refueling is determined from the estimates shown in Table 2A-2. Again an independent random number is generated with a value between 0.0 and 1.0. If the value is less than the probability shown in Table 2A-2 for that initial fill level, the tank is assumed to be filled up. When a partial fill is indicated, another random number between 0.0 and 1.0 is generated. This random number is used in conjunction with the NORMINV function in

Excel to generate a random level of the standard normal deviate, or the number of standard deviations to add to the mean estimate for the volume of fuel added during a partial fill-up. The values for the mean and standard deviations for volume of fuel added are shown in Table 2A-4. As discussed in Section 2A.2, whenever the initial fuel tank level is 0.5 or greater, we assume that the tank is filled up.

Occasionally, the volume of fuel added during a partial fill will exceed the capacity of the tank. This occurs when the random number generator produces a large positive number of standard deviations to be added to the mean fuel volume typically added during a partial fill. In these cases, we set the final tank level after refueling to 100%.

The type of fuel added, ethanol or non-ethanol blend, is determined both by the level of brand loyalty and the mix of fuels available in the local area. As discussed in Section 2A.4, brand loyalty is estimated to be 36%. Again, an independent random number is generated with a value between 0.0 and 1.0. If the value is less than 0.36, the type of fuel added is assumed to be the same as that added during the last refueling. Otherwise, the probability of refueling with any particular fuel is assumed to be independent of the previous fuel used. The probabilities of refueling with a non-ethanol blend and an ethanol blend are the market shares of the respective fuels. This is selection is made by choosing a new random number.

We then determine the quality of the fuel in the tank after the refueling event. The ethanol concentration of the tank fuel is simply the ethanol concentration of the fuel prior to refueling plus that of the fuel added during refueling, each weighted by their respective volumes. We assume that the fuel tank contains some volume of fuel, even when it indicates empty. Consistent with CARB in their assessment of commingling, we assume that this tank "heel" is 10% of the tank capacity. The "ethanol" portion of the ethanol blend is assumed to be 95% pure ethanol (i.e., it contains 5% denaturant). This denaturant is assumed to have the same RVP as the non-oxygenated gasoline.

Calculating the RVP of the gasoline blend after refueling is more complicated. We first calculate the RVP of the hydrocarbon portion of the fuel after refueling in the same way as described above for the ethanol concentration. The RVP of hydrocarbons blend linearly or ideally, so we simply weight the RVP of the hydrocarbon portion of the fuel left in the tank just prior to refueling (adjusted downward for weathering as indicated above) with that of the new fuel by their respective contributions to the total volume of fuel in the tank after refueling. We then increase this RVP based on the concentration of ethanol in the tank. As described in Section 2A.3, we assume that ethanol's impact on RVP is constant between 2 and 10 vol% and a function of the RVP of the hydrocarbon blendstock, as discussed above. Between zero and 2 vol%, we assume that its RVP effect increases linearly up to its full effect.

At this point, the vehicle has been refueled and we have determined the quality of the fuel currently in the tank. The next step is to repeat the entire process described above, starting with a new level at which the tank is refueled once again.

Once a vehicle has been refueled 500 times, we determine the RVP and ethanol concentration of the fuel in the tank over a range of fuel tank fill levels. We split the full range of possible tank fill levels into 10 discrete segments, each representing a 10% range of tank fill level (e.g., 20-30% full). We then determine which tank fill levels the vehicle will be driven through prior to the next refueling. For example, if a vehicle is refueled to 100% of tank capacity and is then driven down to 1/8 full before its next refueling, its tank moves from 100% full to 90% full to 80% full, etc. until it reaches 12.5% full. Thus, in this example, the tank was never in the range of 0-10% full. We assume that the vehicle spends the same amount of time and accumulates the same amount of VMT at each tank fill level between its starting and ending points. (This is simply equivalent to assuming that vehicles are driven differently depending on their level of fuel tank fill level; a safe assumption.) The RVP of the fuel in the tank is adjusted at each fill level as the vehicle is being driven, including the effect of weathering. The same is done for ethanol concentration. For each segment of fuel tank fill level, the RVP and ethanol concentration occurring between each set of refueling events is averaged.

The entire process is then repeated 50 times. Overall, both RVP and ethanol concentration versus tank fuel fill level is tracked for 25,000 refuelings (500 refuelings per model pass-through times 50 model pass-throughs). Overall averages are then determined and retained for analysis.

One output of the model which is independent of the RVP levels of the fuels is the distribution of the fuel tank levels of vehicle on the road at any one time. This distribution is shown in Table 2A-7.

Table 2A-7. Distribution of Fuel Tank Fill Levels for the In-Use Fleet

Range of Fuel Tank Fill Level		
Lower Limit	Upper Limit	% of Vehicles
0%	10%	7.6%
10%	20%	9.4%
20%	30%	12.9%
30%	40%	12.5%
40%	50%	12.2%
50%	60%	10.6%
60%	70%	9.4%
70%	80%	8.7%
80%	90%	8.4%
90%	100%	8.2%

As can be seen, the most frequent onroad fuel tank fill levels are between 20% to 50%. This distribution will be used to weight the effect of commingling which occurs for each range of fuel tank fill level.

2A.6 Modeling Results

We performed the procedure described in Section 2A.5. for a set of base gasoline RVP levels ranging from roughly 7 RVP to 9 RVP and for the two types of ethanol blending (matched RVP and increased RVP). An example of the sequence of calculations is as follows:

1) Select the RVP of non-oxygenated gasoline (E0), the RVP of the ethanol blend (E10), and the market share of E10,
2) Begin with a tank full of non-oxygenated gasoline,
3) Choose a random number which is used to probabilistically determine: a) the level at which the tank is being refueled, b) the level to which the tank is filled, c) the volume of fuel thus being added, and d) the type of fuel used to fill the tank (E0 or E10),
4) Determine which tank fill levels the vehicle passed through between the prior fill level and the point at which it was refilled and determine the fuel RVP at each 10% increment in tank fill level using the weathering equation,
5) Determine the RVP of the hydrocarbon portion of the fuel at the time of refill using the weathering equation,
6) Determine the concentration of ethanol in the refilled fuel tank using the ethanol concentration of the fuel after the prior fill-up, the volume of fuel in the tank at the time of refill, the ethanol concentration of the fuel used to refill the tank currently and the volume of fuel added during this refill,
7) Determine the RVP of the hydrocarbon portion of the fuel after refill by weighting the RVP of the hydrocarbon portion of the fuel in the tank at the time of refueling and the RVP of hydrocarbon portion of the fuel being added by the volume of the hydrocarbon portion of the fuel in the tank at the time of refill and the volume of the hydrocarbon portion of the fuel being added during refueling, respectively,
8) Determine the RVP of the total fuel in the tank after refueling from the RVP of the hydrocarbon portion of the fuel from step 6 and the effect of ethanol on RVP using its concentration from step 5.
9) Return to step 2) and proceed through 500 refuelings.

Once the model has been applied to 500 refuelings (essentially the life of the vehicle), the results are compiled. The average RVP level for each interval of tank fill level is determined. For example, over 500 refuelings, approximately 200 have the tank being refilled when it was less than one-eighth full, so that the vehicle was driven when the tank was 10% full. For these 200 occurrances, the tank RVP level is averaged. This becomes the average RVP at a fuel tank fill level of 10%. Approximately 260 refueling involve the vehicle being driven when the fuel tank fill level is 20%. Fuel RVP is again averaged for these 260 situations. The process is repeated for a 30% fuel tank fill level, 40%, and so on through 100% full (which occurs every time the tank is completely filled up). The RVP predictions of the model for various mixes of 9 RVP non-oxygenated gasoline and a 10 RVP ethanol blend are shown in Tables 2A-8 through 2A-13. The last line of each table shows the weighted average RVP level using the distribution of in-use fuel tank fill levels shown above in Table 2A-7.

Table 2A-8. In-Use Fuel Tank RVP Levels – 9 RVP CG with Ethanol Waiver (psi)

	Ethanol Blend Market Share														
Fuel Tank Fill Level	0%	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	100%
5%	8.15	8.19	8.26	8.35	8.52	8.67	8.79	8.90	8.98	9.05	9.11	9.15	9.17	9.17	9.17
15%	8.23	8.27	8.33	8.42	8.58	8.74	8.87	8.97	9.05	9.12	9.18	9.22	9.24	9.25	9.25
25%	8.29	8.33	8.40	8.49	8.65	8.81	8.93	9.04	9.11	9.19	9.24	9.29	9.30	9.31	9.31
35%	8.35	8.39	8.45	8.55	8.71	8.87	8.99	9.09	9.17	9.25	9.30	9.35	9.36	9.37	9.37
45%	8.40	8.44	8.50	8.60	8.77	8.93	9.05	9.15	9.23	9.31	9.35	9.40	9.41	9.41	9.41
55%	8.44	8.48	8.56	8.65	8.82	8.98	9.11	9.21	9.29	9.36	9.40	9.45	9.46	9.46	9.46
65%	8.50	8.55	8.62	8.71	8.89	9.05	9.17	9.27	9.35	9.43	9.46	9.51	9.52	9.52	9.52
75%	8.58	8.62	8.70	8.79	8.97	9.13	9.25	9.35	9.43	9.50	9.54	9.58	9.59	9.60	9.60
85%	8.66	8.71	8.78	8.87	9.05	9.22	9.34	9.44	9.52	9.59	9.63	9.67	9.68	9.68	9.68
95%	8.75	8.80	8.87	8.97	9.15	9.31	9.43	9.53	9.61	9.68	9.72	9.76	9.77	9.77	9.77
Wtd.Avg.	8.42	8.47	8.53	8.63	8.80	8.96	9.08	9.18	9.26	9.34	9.38	9.42	9.44	9.44	9.44

Table 2A-9. In-Use Fuel Tank RVP Levels – 7.8 RVP CG with Ethanol Waiver (psi)

	Ethanol Blend Market Share														
Fuel Tank Fill Level	0%	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	100%
5%	7.08	7.13	7.20	7.30	7.50	7.64	7.79	7.91	8.01	8.10	8.15	8.19	8.21	8.22	8.22
15%	7.14	7.19	7.26	7.36	7.56	7.71	7.85	7.97	8.07	8.15	8.21	8.25	8.27	8.28	8.28
25%	7.20	7.25	7.31	7.41	7.62	7.76	7.91	8.03	8.12	8.21	8.27	8.30	8.32	8.34	8.34
35%	7.24	7.30	7.36	7.46	7.67	7.81	7.96	8.08	8.17	8.26	8.31	8.35	8.37	8.38	8.38
45%	7.29	7.34	7.41	7.51	7.71	7.86	8.01	8.13	8.22	8.30	8.35	8.40	8.41	8.42	8.42
55%	7.33	7.38	7.45	7.55	7.76	7.92	8.06	8.18	8.27	8.35	8.40	8.44	8.45	8.46	8.46
65%	7.38	7.43	7.50	7.61	7.82	7.97	8.12	8.23	8.33	8.40	8.45	8.49	8.51	8.51	8.51
75%	7.44	7.49	7.57	7.67	7.88	8.04	8.19	8.30	8.40	8.47	8.52	8.55	8.57	8.58	8.58
85%	7.51	7.56	7.64	7.75	7.95	8.12	8.27	8.38	8.47	8.54	8.59	8.62	8.64	8.65	8.65
95%	7.59	7.64	7.72	7.82	8.03	8.19	8.35	8.45	8.55	8.61	8.67	8.70	8.72	8.73	8.73
Wtd.Avg.	7.31	7.36	7.43	7.53	7.74	7.89	8.04	8.15	8.25	8.33	8.38	8.42	8.44	8.45	8.45

Table 2A-10. In-Use Fuel Tank RVP Levels – 6.8 RVP CG with Ethanol Waiver (psi)

	Ethanol Blend Market Share														
Fuel Tank Fill Level	0%	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	100%
5%	6.19	6.24	6.31	6.43	6.63	6.82	6.96	7.09	7.19	7.29	7.35	7.40	7.41	7.42	7.43
15%	6.24	6.29	6.37	6.48	6.68	6.86	7.02	7.13	7.24	7.33	7.40	7.45	7.46	7.47	7.48
25%	6.29	6.34	6.41	6.53	6.73	6.91	7.07	7.18	7.29	7.38	7.45	7.50	7.51	7.52	7.53
35%	6.33	6.38	6.46	6.57	6.77	6.95	7.11	7.23	7.34	7.42	7.49	7.53	7.55	7.56	7.57
45%	6.36	6.42	6.49	6.61	6.81	7.00	7.16	7.27	7.38	7.47	7.53	7.57	7.59	7.59	7.60
55%	6.40	6.45	6.53	6.65	6.86	7.04	7.20	7.31	7.42	7.51	7.57	7.61	7.62	7.63	7.64
65%	6.44	6.50	6.57	6.69	6.90	7.09	7.25	7.36	7.47	7.56	7.61	7.65	7.67	7.67	7.68
75%	6.50	6.55	6.63	6.75	6.96	7.15	7.31	7.42	7.53	7.61	7.67	7.71	7.72	7.72	7.73
85%	6.56	6.61	6.69	6.81	7.02	7.21	7.37	7.49	7.59	7.67	7.73	7.77	7.78	7.79	7.79
95%	6.63	6.68	6.76	6.88	7.09	7.28	7.44	7.55	7.66	7.74	7.79	7.84	7.85	7.85	7.86
Wtd.Avg.	6.39	6.44	6.51	6.63	6.84	7.02	7.18	7.30	7.40	7.49	7.55	7.59	7.61	7.61	7.62

Table 2A-11. In-Use Fuel Tank RVP Levels as – 9 RVP Gasoline with No Ethanol Waiver

	Ethanol Blend Market Share														
Fuel Tank Fill Level	0%	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	100%
5%	8.15	8.17	8.20	8.26	8.33	8.38	8.40	8.41	8.40	8.36	8.32	8.26	8.23	8.20	8.19
15%	8.23	8.24	8.28	8.33	8.40	8.45	8.47	8.47	8.46	8.43	8.39	8.33	8.30	8.28	8.27
25%	8.29	8.31	8.34	8.39	8.47	8.51	8.54	8.54	8.53	8.50	8.45	8.40	8.37	8.35	8.33
35%	8.35	8.37	8.40	8.45	8.52	8.58	8.60	8.60	8.59	8.56	8.51	8.45	8.42	8.40	8.39
45%	8.39	8.42	8.45	8.50	8.58	8.63	8.65	8.66	8.65	8.61	8.56	8.50	8.47	8.45	8.43
55%	8.44	8.47	8.50	8.55	8.63	8.69	8.71	8.72	8.71	8.67	8.62	8.55	8.52	8.50	8.48
65%	8.50	8.53	8.56	8.62	8.70	8.75	8.78	8.78	8.77	8.73	8.68	8.62	8.58	8.56	8.54
75%	8.58	8.60	8.64	8.69	8.77	8.83	8.86	8.86	8.85	8.81	8.76	8.69	8.66	8.63	8.62
85%	8.67	8.69	8.72	8.78	8.86	8.92	8.95	8.95	8.94	8.90	8.85	8.78	8.74	8.72	8.70
95%	8.76	8.78	8.81	8.87	8.95	9.01	9.04	9.04	9.03	8.99	8.94	8.87	8.84	8.81	8.79
Wtd.Avg.	8.43	8.45	8.48	8.53	8.61	8.66	8.69	8.69	8.68	8.64	8.60	8.53	8.50	8.48	8.46

Table 2A-12. In-Use Fuel Tank RVP Levels – 8 RVP Gasoline with No Ethanol Waiver (psi)

Fuel Tank Fill Level	Ethanol Blend Market Share														
	0%	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	100%
5%	7.26	7.28	7.32	7.36	7.44	7.50	7.53	7.53	7.52	7.48	7.43	7.36	7.33	7.31	7.28
15%	7.33	7.35	7.38	7.43	7.50	7.57	7.59	7.60	7.57	7.55	7.49	7.42	7.39	7.37	7.35
25%	7.39	7.41	7.44	7.49	7.56	7.62	7.64	7.66	7.64	7.60	7.56	7.48	7.45	7.43	7.41
35%	7.43	7.45	7.49	7.54	7.62	7.68	7.70	7.71	7.69	7.66	7.60	7.53	7.50	7.47	7.46
45%	7.47	7.50	7.53	7.59	7.67	7.73	7.75	7.76	7.74	7.71	7.65	7.57	7.54	7.52	7.50
55%	7.52	7.54	7.57	7.63	7.72	7.78	7.80	7.81	7.79	7.76	7.70	7.62	7.59	7.56	7.54
65%	7.57	7.59	7.63	7.69	7.77	7.84	7.86	7.87	7.85	7.81	7.75	7.67	7.64	7.61	7.59
75%	7.63	7.66	7.69	7.75	7.84	7.91	7.93	7.94	7.92	7.88	7.82	7.74	7.70	7.67	7.66
85%	7.71	7.73	7.77	7.83	7.92	7.98	8.01	8.02	7.99	7.96	7.90	7.82	7.78	7.75	7.73
95%	7.79	7.81	7.85	7.91	8.00	8.06	8.09	8.10	8.07	8.04	7.98	7.90	7.86	7.83	7.81
Wtd.Avg.	7.50	7.52	7.56	7.61	7.69	7.76	7.78	7.79	7.77	7.73	7.68	7.60	7.57	7.54	7.52

Table 2A-13. In-Use Fuel Tank RVP Levels – 7 RVP Gasoline with No Ethanol Waiver (psi)

Fuel Tank Fill Level	Ethanol Blend Market Share														
	0%	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%	100%
5%	6.37	6.40	6.43	6.49	6.57	6.63	6.66	6.66	6.65	6.61	6.56	6.48	6.44	6.41	6.40
15%	6.43	6.45	6.48	6.54	6.62	6.68	6.71	6.71	6.70	6.66	6.61	6.54	6.49	6.47	6.45
25%	6.47	6.50	6.53	6.59	6.68	6.73	6.76	6.76	6.75	6.71	6.66	6.59	6.54	6.51	6.50
35%	6.51	6.54	6.58	6.64	6.72	6.78	6.81	6.81	6.79	6.76	6.70	6.63	6.58	6.56	6.54
45%	6.55	6.58	6.62	6.68	6.77	6.82	6.85	6.85	6.84	6.80	6.74	6.67	6.62	6.59	6.58
55%	6.59	6.61	6.66	6.72	6.81	6.87	6.90	6.90	6.89	6.84	6.78	6.71	6.66	6.63	6.61
65%	6.63	6.66	6.70	6.77	6.86	6.92	6.96	6.95	6.94	6.89	6.83	6.75	6.70	6.67	6.65
75%	6.69	6.72	6.76	6.82	6.92	6.98	7.02	7.01	7.00	6.95	6.89	6.81	6.76	6.73	6.71
85%	6.75	6.78	6.82	6.89	6.98	7.05	7.08	7.08	7.06	7.02	6.95	6.88	6.82	6.79	6.77
95%	6.82	6.85	6.89	6.96	7.05	7.11	7.15	7.15	7.13	7.08	7.02	6.94	6.89	6.86	6.84
Wtd.Avg.	6.57	6.60	6.64	6.70	6.79	6.85	6.88	6.88	6.86	6.82	6.76	6.69	6.64	6.61	6.60

The next step is to estimate the impact of commingling on in-use RVP. We use the in-use tank RVP levels shown in the previous six tables for ethanol blend market shares of zero and 100% to represent situations where no commingling occurs. In the absence of commingling at intermediate levels of ethanol blend market share, the RVP should vary linearly between those found at zero and 100%. The impact of commingling is then the difference between the actual level of RVP estimated by the model and the RVP estimated from the zero and 100% ethanol blend market share RVP levels. Table 2A-14 shows the impact of commingling for the case where gasoline RVP is 9 psi and ethanol blends are allowed a 1.0 psi RVP waiver.

Table 2A-14. Commingling as a Function of Fuel Tank Fill Level and Ethanol Blend Market Share – 9 RVP CG with Ethanol Waiver

Fuel Tank Fill Level	Ethanol Blend Market Share												
	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%
5%	0.016	0.049	0.101	0.167	0.213	0.235	0.234	0.220	0.183	0.132	0.073	0.036	0.013
15%	0.017	0.047	0.096	0.164	0.210	0.229	0.228	0.214	0.179	0.129	0.070	0.037	0.015
25%	0.019	0.049	0.098	0.166	0.210	0.228	0.230	0.217	0.180	0.130	0.072	0.036	0.014
35%	0.021	0.049	0.097	0.170	0.217	0.234	0.235	0.222	0.184	0.134	0.071	0.037	0.015
45%	0.023	0.051	0.101	0.175	0.224	0.243	0.243	0.229	0.192	0.138	0.073	0.039	0.013
55%	0.023	0.052	0.105	0.181	0.232	0.251	0.252	0.240	0.197	0.143	0.076	0.042	0.015
65%	0.025	0.054	0.110	0.185	0.238	0.259	0.260	0.246	0.201	0.147	0.078	0.043	0.014
75%	0.025	0.055	0.112	0.187	0.240	0.263	0.263	0.250	0.204	0.150	0.078	0.042	0.013
85%	0.026	0.055	0.112	0.186	0.242	0.265	0.266	0.251	0.206	0.150	0.078	0.042	0.013
95%	0.025	0.055	0.112	0.186	0.242	0.265	0.266	0.252	0.206	0.151	0.079	0.043	0.013
Wtd.Avg.	0.022	0.051	0.104	0.176	0.226	0.246	0.246	0.233	0.192	0.140	0.074	0.039	0.014

As can be seen, the impact of commingling increases slightly moving from low levels of fuel tank fill level to high levels. As found by previous studies of commingling, the impact of commingling is lowest when either E0 or E10 fuels predominate the market and peaks when the mix of E0 and E10 is approximately 50/50. Again, the weighted average of the commingling impact is determined by applying weighting the commingling impact at each fuel tank fill level by the distribution of fill levels in-use shown in Table 2A-7.

Table 2A-15 shows the weighted average commingling impacts for the six fuel cases.

Table 2A-15. Weighted Average Commingling Impact for Various Sets of E0 and E10 Fuels (psi)

E0/E10 RVP Level	Ethanol Blend Market Share												
	2%	5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	95%	98%
9/10	0.022	0.060	0.102	0.171	0.227	0.249	0.249	0.227	0.199	0.143	0.084	0.045	0.020
7.8/8.9	0.029	0.065	0.110	0.201	0.239	0.273	0.274	0.255	0.218	0.160	0.082	0.043	0.019
7/8.2	0.028	0.067	0.122	0.203	0.265	0.299	0.290	0.275	0.236	0.173	0.094	0.046	0.015
9/9	0.022	0.051	0.104	0.176	0.226	0.246	0.246	0.233	0.192	0.140	0.074	0.039	0.014
8/8	0.021	0.055	0.110	0.189	0.249	0.269	0.278	0.253	0.218	0.160	0.080	0.045	0.019
7/7	0.027	0.065	0.125	0.212	0.267	0.298	0.294	0.277	0.233	0.172	0.096	0.047	0.017

Ethanol use in the three RFS rule fuel cases (Reference, RFS, and EIA) occurs predominately under three situations: 1) 9 RVP CG with an RVP waiver for ethanol, 2) 7.8 RVP CG with an RVP waiver for ethanol, and 3) 7 RVP RFG. In order to simplify application of the impact of commingling to our emission modeling, we averaged the commingling impacts for these situations from Table 2A-15 and applied that to the entire U.S. as a function of ethanol blend market share. This average set of commingling impacts is shown in Table 2A-16.

Table2A-16. Commingling Impact Applied in RFS Rule Emission Modeling

Ethanol Blend Market Share	Commingling Impact (psi)
0%	0
2%	0.026
5%	0.064
10%	0.113
20%	0.194
30%	0.244
40%	0.273
50%	0.272
60%	0.253
70%	0.217
80%	0.159
90%	0.087
95%	0.045
98%	0.019
100%	0.000