Replacing the Volume & Octane Loss of Removing MTBE From Reformulated Gasoline Ethanol RFG vs. All Hydrocarbon RFG

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Ethanol RFG vs. All Hydrocarbon RFG

This analysis was prepared by Robert E. Reynolds, president of Downstream Alternatives Inc. (DAI). DAI provides consultation services to wide variety of clients with fuel related interests, including industry and government (both federal and states). Mr. Reynolds is widely recognized as an ethanol industry expert. He has authored hundreds of articles as well as extensive studies on ethanol related topics as well as articles on fuel quality, fuel specifications, and petroleum industry logistics. Mr. Reynolds is a member of SAE International, ASTM International (subcommittees DO2. A and D02.E) and the National Conference on Weights and Measures (NCWM) serving on its petroleum subcommittee. Mr. Reynolds has also served on various state government task forces on fuel issues.

Summary

Several states using reformulated gasoline (RFG) to combat smog have banned MTBE because of water contamination concerns. These states must replace MTBE with ethanol to comply with the RFG oxygenate requirement. In addition to maintaining the minimum oxygen requirement, refiners must maintain octane and environmental parameters while filling the 11% volume void left when MTBE is removed.

Some people have suggested that replacing MTBE without ethanol would be cheaper and require less petroleum inputs. They want to eliminate the RFG oxygenate requirement. This analysis compares the volume, octane, and cost implications of ethanol-blended RFG with that of an all hydrocarbon RFG alternative which would, or could, be used if the oxygenate requirement is waived.

Comparison of Ethanol-Blended and All Hydrocarbon RFG

Fuel Type	**Reduction in Refinery Hydrocarbon Purchases with Ethanol**	**Reduction in Input Costs with Ethanol (cpg)**
CARB Summer Grade	0.7v%	0.696
CARB Winter Grade	3.2v%	1.669
Federal Summer Grade	5.0v%	1.610
Federal Winter Grade	7.5v%	2.435

As can be seen in the above table, in every case analyzed, ethanol contributes to a net volume gain compared to an all hydrocarbon RFG. Further, these supply gains are achieved at a cost savings ranging from 0.7 cents per gallon (cpg) to 2.4 cpg compared to all hydrocarbon gasoline.

Using ethanol, instead of only hydrocarbons, to replace MTBE in RFG nationwide, can contribute in excess of 1.6 billion gallons per year to the supply picture, thereby reducing imports and refinery purchases by a similar amount.

Introduction

Several states that are required to use reformulated gasoline (RFG) containing oxygenates (to combat ozone pollution) have banned one oxygenate, MTBE, due to ground water contamination concerns. The only practical remaining oxygenate is ethanol. In order to accommodate ethanol's blending characteristics, especially in summer grade RFG, it is necessary to adjust the base fuel by removing certain high volatility components to ensure vapor pressure requirements can be met. This adjustment has been characterized as resulting in a net loss in available volume with ethanol use. However, it is important to note that, with or without ethanol, the 11% volume from MTBE removal must be made up, and it must be done with components that maintain octane quality and volatility parameters. So the real question is: does ethanol use increase or reduce the volume shortfall resulting from the removal of MTBE? As this analysis demonstrates, in all cases assessed here, ethanol use has a net positive impact on RFG supplies.

The following comparisons are prepared to provide a simple, easy to understand, estimate of how the lost MTBE volume might be made up, both with and without ethanol.

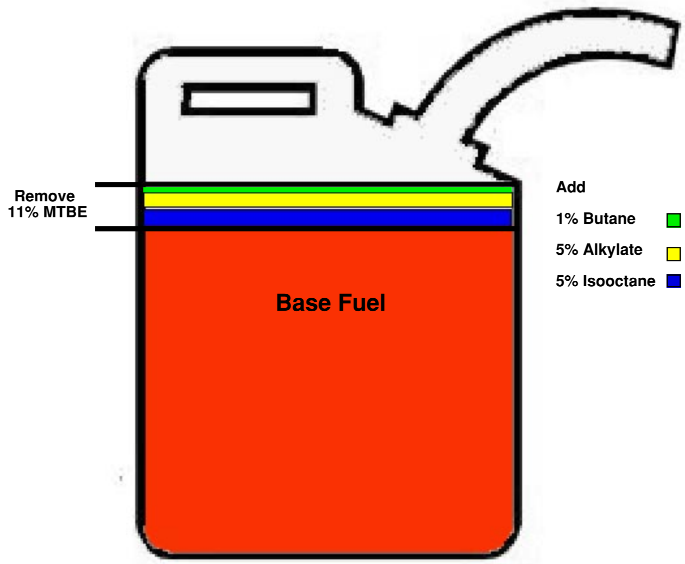
The calculations are manual, focusing on the key gasoline components and their established values. The comparisons are not based on linear programing. Actual fuel composition will vary from refinery to refinery based on a variety of inputs including feedstock input, finished product slates, and processing equipment within a given refinery. Refiners must also comply with the EPA Complex or CARB Predictive models, as applicable, and comply with toxics requirements. These items have not been assessed here, although the addition of isooctane and alkylate would tend to aid in some aspects of compliance.

The California Air Resources Board (CARB) sets requirements for California RFG, referred to hereafter as CARB summer and winter grades.

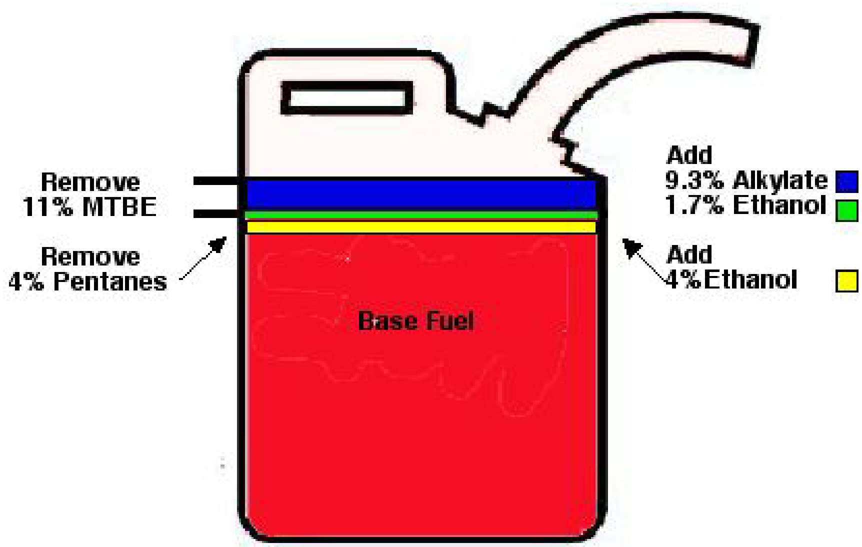
Since requirements are different for California RFG, (NOx calculations in the Predictive Model limit ethanol content to 5.7v%) and federal RFG, and also between winter and summer grades, comparisons are offered for 87 octane unleaded gasoline in each of these categories.

The following graphics provide a visual presentation of one possible composition for a gallon of gasoline in each category followed by a discussion of what went into the calculations, (assumptions) and then comments on each category.

CARB Summer All Hydrocarbon
Outside refinery volume replacement 10v%



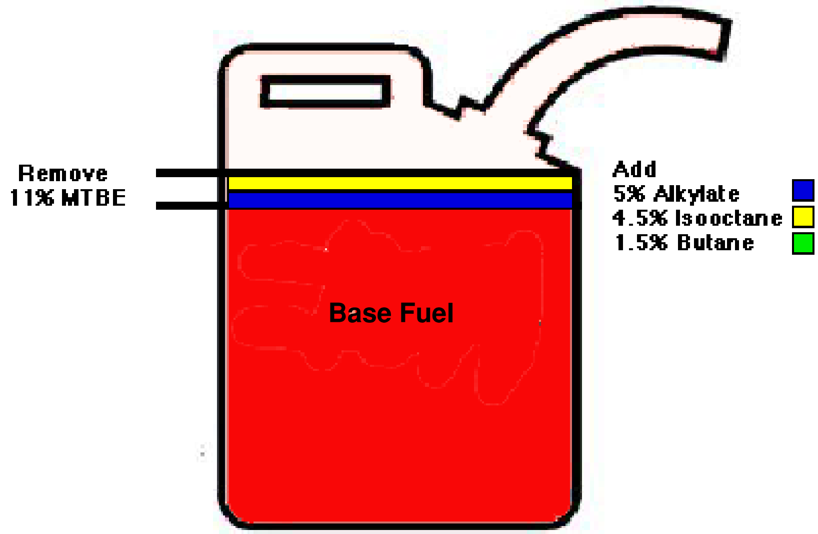
CARB Summer 5.7v% Ethanol
Outside refinery volume replacement 9.3v% (exclusive of ethanol)



NOTE: The excess pentanes would be used in gasoline exported to Arizona and Nevada (Federal RFG or conventional) thereby reducing the total outside refinery purchase in the above example from 9.3v% to as low as 5.3v%

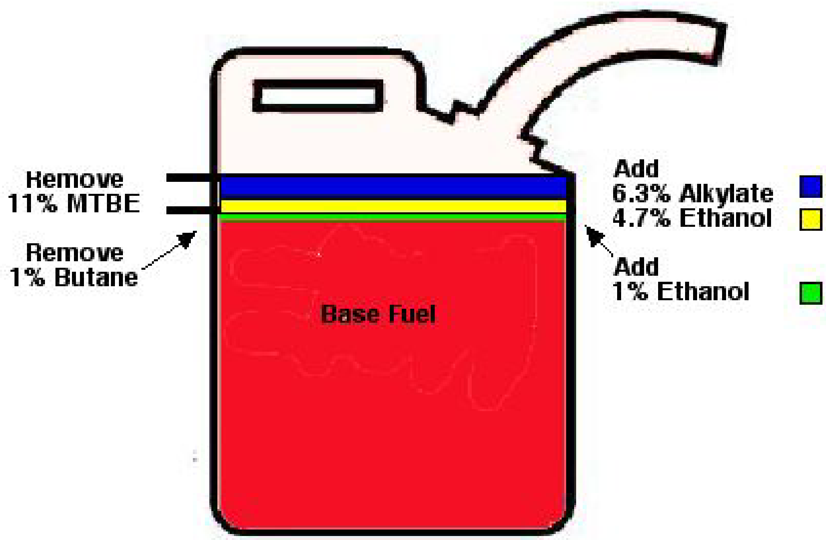
CARB Winter All Hydrocarbon

Outside refinery volume replacement 9.5v%

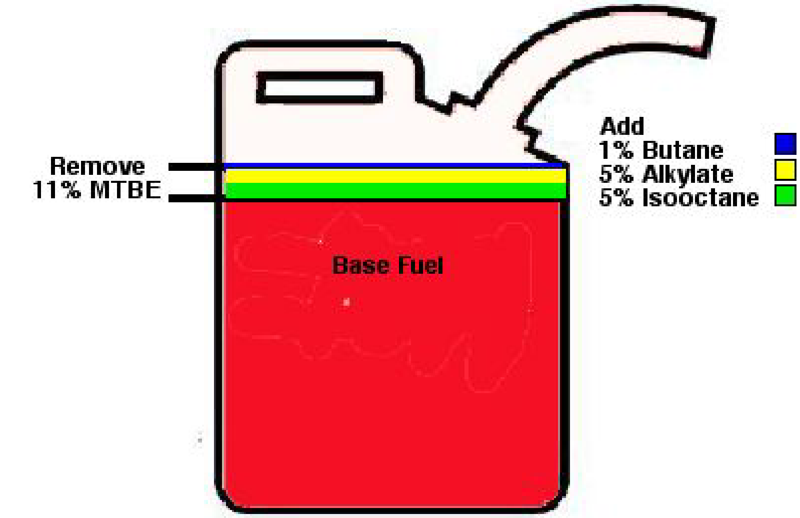


CARB Winter 5.7v% Ethanol

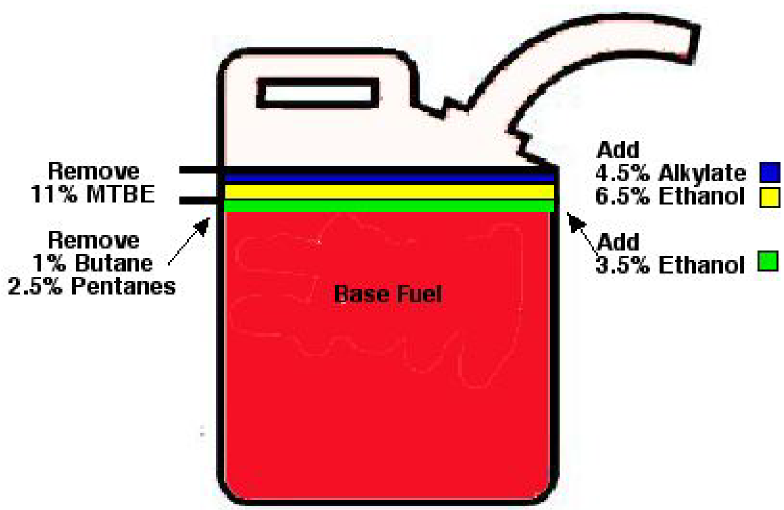
Outside refinery volume replacement 6.3v% (exclusive of ethanol)



Federal RFG Summer All Hydrocarbon
Outside refinery colume replacement 10.0v%

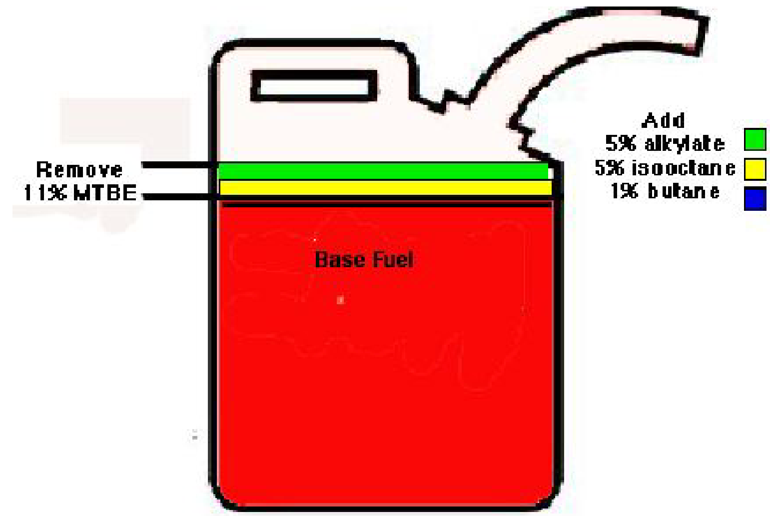


Federal RFG Summer 10v% Ethanol
Outside refinery volume replacement 4.5v% (exclusive of ethanol)



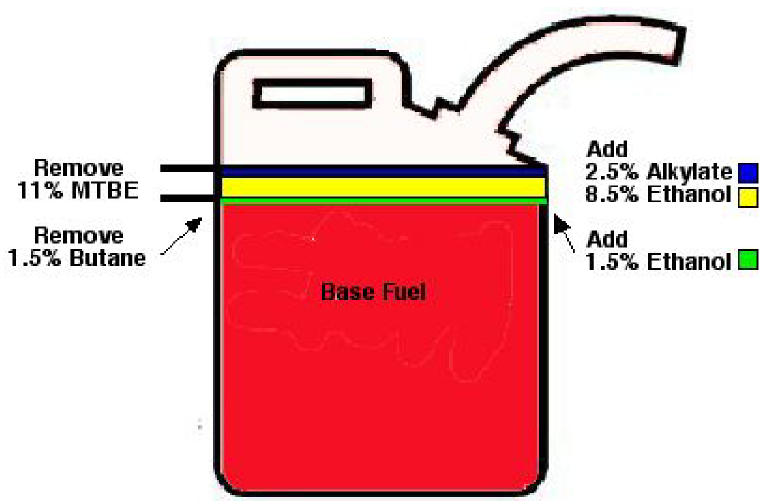
Federal RFG Winter All Hydrocarbon

Outside refinery volume replacement 10v%



Federal RFG Winter 10v% Ethanol

Outside refinery volume replacement 2.5v% (exclusive of ethanol)



Starting Assumptions

Base CARB and federal RFG at 87 (R+M)/2 with 11v% MTBE. RVP as indicated in example title. After removing MTBE remaining base fuel is 84 (R+M)/2 and RVP is as indicated in example title in parentheses.

Component	Blending Vapor Pressure	Blending Octane Number (R+M)/2	Cost-premium to gasoline (cpg)
CARB summer-MTBE blend	7.0	87	na
CARB winter-MTBE blend	10.0	87	na
Federal summer RFG-MTBE blend	7.0	87	na
Federal winter RFG-MTBE blend	13.5	87	na
MTBE	8.0	111	22
Ethanol (1)	18.0/25.0	112.5	0 (net of credits)
B Alkylate (2)	2.6	94	15
Isooctane (2)	1.8	100	35
N Butane	52	92	(20)
Mixed Pentanes (N/I@ 30/70)	19	82.6	(25)
Incremental octane cost	-	-	0.5 (per gallon)

(1) The blending vapor pressure (bvp) of ethanol is nonlinear. For 10v% ethanol blends a bvp of 18.0 psi is used. For 5.7v% ethanol blends, a bvp of 25.0 psi is used.
(2) The supply availability of alkylate in sufficient volumes to blend all RFG without ethanol is uncertain, and for isooctane even more uncertain. The premium for isooctane is estimated, as insufficient volumes are traded to establish historic price patterns. Price premiums for alkylate and isooctane could exceed those cited above, especially if they are the sole component used to replace MTBE.

CARB Summer - All Hydrocarbon 7.0 RVP (Base fuel 6.9 RVP)

Action	Volume% Contribution	RVP Contribution	Octane Contribution	Cost Impact Contribution (cpg)
Base fuel	89	6.141	74.760	(2.42)
Isooctane	5	0.090	5.000	+1.75
Alkylate	5	0.130	4.700	+0.75
Butane add back	1	0.520	0.920	(0.20)
Totals	100	6.881	85.380	(0.12)
Incremental octane cost				+0.81
Net projected cost impact				+0.69

CARB summer grades would have a 6.9 psi RVP after removing the MTBE. The addition of 5v% alkylate and 5v% isooctane would allow the addition of 1 v% butane resulting in an RVP of 6.881. However the octane in this example only comes to 85.38 (R+M)/2 which would require some refinery adjustment to obtain the remaining 1.62 octane numbers, probably using aromatics.

Removing the MTBE and adding butane reduces the cost of the base fuel while adding alkylate and isooctane increase the cost. The net affect in this example is a finished fuel that is 0.12 cpg lower, prior to making up the octane shortfall and 0.69 cpg higher after adding octane cost.

The net outside refinery volume replacement is 10v%.

CARB Summer - 5.7v% Ethanol 7.0 RVP (Base fuel 6.9 RVP)

Action	Volume% Contribution	RVP Contribution	Octane Contribution	Cost Impact Contribution (cpg)
Base fuel	89	6.1410	74.760	(2.420)
Add 5.7v% ethanol	5.7	1.4250	6.413	0.000
Remove 4v% Mixed Pentanes	(4.0)	(0.7600)	(3.304)	+1.000
Add Alkylate	9.3	0.2418	8.742	+1.395
Totals	100	7.0480	86.611	(0.025)
Incremental octane cost				+0.019
Net projected cost impact				(0.006)

In the case of using ethanol in CARB summer RFG, it would be necessary to back out 4% pentanes, reducing the volume benefit of the addition of the 5.7v% ethanol. To make up the remaining volume loss from MTBE removal would then require the addition of 9.3v% alkylate. The RVP would be comparable to the all hydrocarbon blend while the octane is 1.231 numbers higher. The cost impact is estimated at a reduction of 0.006 cpg compared to the base fuel containing MTBE and 0.0696 cpg less than the hydrocarbon alternative.

The net outside refinery volume replacement (exclusive of ethanol) is 9.3v% versus 10v% for the all hydrocarbon alternative (see discussion below). Those refiners with alkylation units will be able to send pentanes removed to the alkylation unit further reducing outside purchases.

Any excess pentanes could be used in conventional gasoline or for federal RFG exported to Arizona and Nevada. Therefore, for total refinery gasoline volume, the actual net refinery purchases may be 4v% less than the 9.3v% cited above.

Note that CARB summer grade is required 9 months per year, the result being that refiners produce CARB summer grade for nearly 10 months or about 83% of annual volume. Thus the 0.7v% volume difference for this grade (compared to the all hydrocarbon alternative) equates to a 0.581% annualized volume gain before considering any pentane inputs to alkylation units or reblending to federal RFG and conventional gasoline for export to other states.

CARB Winter - All Hydrocarbon10.0 RVP (Base fuel 10.2 RVP)

Action	Volume% Contribution	RVP Contribution	Octane Contribution	Cost Impact Contribution (cpg)
Base fuel	89.0	9.078	74.760	(2.420)
Butane add back	1.5	0.780	1.380	(0.300)
Alkylate	5.0	0.130	4.700	+0.750
Isooctane	4.5	0.081	4.500	+1.575
Totals	100	10.069	85.340	(0.395)
Incremental octane cost				+0.830
Net projected cost impact				+0.435

For the CARB winter grade, a targeted RVP of 10 psi has been used. Removing MTBE from the fuel increases the remaining base fuel RVP to 10.2 psi. The addition of 5v% alkylate and 4.5v% isooctane allows the add back of 1.5v% butane while still keeping the RVP on target. However octane quality is still a problem with the resulting octane 1.66 numbers below the desired level. This would need to be made up through refinery processing such as increased reforming severity which reduces processing yields slightly. The impact on cost is a reduction of 0.395 cpg per gallon exclusive of processing costs to increase octane and estimated to be an increase of 0.435 after incremental octane costs.

The net outside refinery volume replacement is 9.5v%.

CARB Winter - 5.7v% Ethanol 10.0 RVP(Base fuel 10.2 RVP)

Action	Volume% Contribution	RVP Contribution	Octane Contribution	Cost Impact Contribution (cpg)
Base fuel	89.0	9.0780	74.760	(2.4200)
5.7v% Ethanol	5.7	1.4250	6.413	0.0000
Remove 1% Butane	(1.0)	(0.5200)	(0.920)	+0.2000
Add 6.3% Alkylate	6.3	0.1638	5.922	+0.9450
Totals	100	10.147	86.175	(1.2750)
Incremental octane cost				+0.0413
Net projected cost impact				(1.2337)

Using 5.7v% ethanol in the CARB winter grade still requires 1v% butane removal and the addition of 6.3v% alkylate. This keeps the RVP on target. Octane is below target by 0.825 numbers which would need to be made up by refinery processing similar to, but not as extreme as, the all hydrocarbon alternative. The net cost impact is a reduction of 1.2337 cpg compared to the former MTBE blend. This is 1.6687cpg lower than the hydrocarbon alternative.

The net outside refinery volume replacement (exclusive of ethanol) is 6.3v% or 3.2v% less than the hydrocarbon alternative. Since CARB winter grade represents only about 2 months of actual refinery production, this represents an annualized 0.544% volume gain compared to the hydrocarbon alternative. After considering the 0.581% annualized gain for summer grade, the net annualized affect is a 1.125% volume gain compared to an annualized hydrocarbon alternative calculation. Again this is prior to considering the use of any removed pentanes as either alkylation feed or as blending components for federal RFG or conventional gasoline exported to Arizona or Nevada.

Federal RFG Summer- All Hydrocarbon 7.2 RVP (Base fuel 7.1 RVP)

Action	Volume% Contribution	RVP Contribution	Octane Contribution	Cost Impact Contribution (cpg)
Base fuel	89.0	6.319	74.76	(2.420)
Isooctane	5.0	0.090	5.00	+1.750
Alkylate	5.0	0.130	4.70	+.750
Butane add back	1.0	0.520	0.92	(0.200)
Totals	100	7.059	85.38	(0.120)
Incremental octane cost				+0.810
Net projected cost impact				+0.690

In the case of federal summer RFG, the results are somewhat different from California summer grade. In the case of an all hydrocarbon replacement strategy, the addition of 5.0v% alkylate and 5.0v% isooctane allows a 1.0v% butane add back while still staying within the RVP limit. Octane is constrained reaching only 85.38 (R+M)/2 in this estimate, necessitating increased refinery processing to make up the 1.62 number shortfall. The cost impact is a reduction of (0.12) cpg prior to the cost of increased octane processing (compared to the original MTBE blend) and an increase of 0.69 cpg after adding incremental octane cost.

The net outside refinery purchase is 10.0v%.

Federal RFG Summer- 10.0% Ethanol 7.2 RVP (Base fuel 7.1 RVP)

Action	Volume% Contribution	RVP Contribution	Octane Contribution	Cost Impact Contribution (cpg)
Base fuel	89	6.319	74.76	(2.420)
Add Ethanol	10	1.800	11.25	+0.000
Remove 1.0% N Butane	(1.0)	(0.52)	(0.92)	+0.200
Remove 2.5% Mixed Pentanes	(2.5)	(0.475)	(2.35)	+0.625
Add 4.5% Alkylates	4.5	0.117	4.23	+0.675
Totals	100	7.241	86.97	(0.920)

The federal RFG summer grade with ethanol is similar to CARB summer grade. However, in the case of federal RFG, there is no penalty in the EPA Complex Model for increasing ethanol content to the 10v% level. This greatly improves flexibility. While it is still necessary to remove 1.0v% butane and 2.5v% pentanes, the addition of 10.0v% ethanol leaves only a requirement for the addition of 4.5v% alkylate.

Such a composition keeps RVP within limits while maintaining octane quality of 87. The net cost impact is a reduction of 0.92 cpg compared to the MTBE blend and a 1.44 cpg improvement over the hydrocarbon alternative.

The net outside refinery volume purchase (exclusive of ethanol) in only 4.5v%, 5.5v% better than the all hydrocarbon alternative. Refiners make federal RFG summer grade for approximately 5 months (i.e. April 8 to September 8). This equates to about 42% of annualized volume. Thus, the 5.5v% gain represents a 2.31% volume gain on an annualized basis.

Federal RFG Winter - All Hydrocarbon 13.5 RVP(Base fuel 14.2 RVP)

Action	Volume% Contribution	RVP Contribution	Octane Contribution	Cost Impact Contribution (cpg)
Base fuel	89	12.638	74.76	(2.42)
Butane add back	1	0.520	0.92	(0.20)
Add Alkylate	5	0.130	4.70	+0.75
Add Isooctane	5	0.090	5.00	+1.75
Totals	100	13.378	85.38	(0.12)
Incremental octane cost				+0.81
Net projected cost impact				+0.69

For the federal RFG winter grade at a target RVP of 13.5 psi, the all hydrocarbon alternative is estimated to require the addition of 5v% alkylate and 5v% isooctane in an effort to maintain octane quality. This would also allow the addition of an additional 1v% butane. The resulting RVP is within limits although octane falls short by 1.62 numbers which would need to be made up with increased refinery processing. The net cost impact compared to the MTBE blend being replaced is a reduction of 0.12 cpg prior to any processing to increase octane and an increase of 0.69 cpg after incremental octane cost.

The net outside refinery volume replacement is 10v%.

Federal RFG Winter - 10.0v% Ethanol 13.5 RVP (Base fuel 14.2 RVP)

Action	Volume% Contribution	RVP Contribution	Octane Contribution	Cost Impact Contribution (cpg)
Base fuel	89	12.638	74.76	(2.42)
Add Ethanol	10	1.800	11.25	0.00
Remove 1.5%Butane	(1.5)	(0.780)	(1.38)	+0.30
Add 2.5% Alkylate	2.5	0.065	2.35	+0.375
Totals	100	13.723	86.98	(1.745)

Winter grade federal RFG with ethanol improves the volume picture compared to summer grade. At the target RVP it is still necessary to back out 1.5v% butane. The addition of 10v% ethanol then requires only 2.5v% alkylate addition. This results in a RVP of 13.723 psi, slightly above the target of 13.5. The octane quality is on target at 86.98 (R+M)/2. The cost is 1.745 cpg less than the MTBE blend and 2.435 cpg less than the hydrocarbon alternative.

The net outside refinery volume replacement (exclusive of ethanol) is only 2.5v% compared to 10v% for the hydrocarbon alternative. This 7.5v% improvement is realized for 7 months equating to an annualized volume gain of 4.37%. When added to the summer grade calculations, this results in an annualized gain of 6.68% compared to the hydrocarbon alternative.

Summary

To recap, the following compares net refinery purchases (exclusive of ethanol) as a representation of volume make up.

	Refinery Hydrocarbon Purchases	Advantage (Disdvantage) With Ethanol Volume %
CARB Summer All Hydrocarbon CARB Summer 5.7v% ETOH (1)	10.0v% 9.3v%	 0.7v%
CARB Winter All Hydrocarbon CARB Winter 5.7v% ETOH (1)	9.5v% 6.3v%	 3.2v%
Federal Summer All Hydrocarbon Federal Summer 10.0v% ETOH	9.5v% 4.5v%	 5.0v%
Federal Winter All Hydrocarbon Federal Winter 10.0v% ETOH	10.0v% 2.5v%	 7.5v%

(1) Does not include pentane credit for alkylation or blending into gasoline for export to Nevada/Arizona which would be 3% to 4% volume improvement.

As can be seen above, ethanol in every case contributes to a net volume gain in these examples. The following looks at net cost impact for the examples in this analysis.

	Advantage (Disadvantage) to MTBE Blend cpg	Advantage (Disadvantage) Ethanol to All Hydrocarbon cpg
CARB Summer All Hydrocarbon CARB Summer 5.7v% ETOH	(0.690) 0.006	 0.6960
CARB Winter All Hydrocarbon CARB Winter 5.7v% ETOH	(0.435) 1.2337	 1.6687
Federal Summer All Hydrocarbon Federal Summer 10.0v% ETOH	(0.690) 0.920	 1.6100
Federal Winter All Hydrocarbon Federal Winter 10.0v% ETOH	(0.69) 1.745	 2.4350

As can be seen in the above summary, ethanol contributes to a reduction in cost compared to the all hydrocarbon options examined in this analysis.

The following compares annualized volume gains from using ethanol in CARB and federal RFG.

Grade	Annual Volume	Ethanol Gain	Volume Gain-Gallons
CARB RFG (1)	**14 billion gallon**	**1.125%**	**157,500,000**
Federal RFG	**22 billion gallons**	**6.680%**	**1,469,600,000**
Total	**36 billion gallons**		**1,627,100,000**

(1) Does not include pentane credit for pentane directed to alkylation or reblended into gasoline exported from California.

The above calulations demonstrate that the use of ethanol to replace MTBE in RFG (in these examples) can contribute in excess of 1.6 billion gallons per year compared to an all hydrocarbon gasoline, thereby reducing imports and refinery purchases by a similar amount. Moreover, these gains can be achieved at costs ranging from 0.696 cents per gallon to 2.435 cents per gallon less than gasoline comprised solely of hydrocarbons.