1995 Reformulated Gasoline Market Affected Refiners Differently

by John Zyren, Charles Dale and Charles Riner

Introduction

The United States has completed its first summer driving season using reformulated gasoline (RFG). Motorists noticed price increases at the retail level, resulting from the increased cost to produce and deliver the product, as well as from the tight supply/demand balance during the summer. This article focuses on the costs of producing RFG as experienced by different types of refiners and on how these refiners fared this past summer, given the prices for RFG at the refinery gate.

RFG Regulatory Requirements

The use of RFG is a result of the Clean Air Act Amendments of 1990 (CAAA). The CAAA cover a wide range of programs aimed at improving air quality, including a program to reduce emissions from automobiles, through the use of (a) oxygenated fuels targeting carbon monoxide emissions and (b) RFG targeting ozone and toxic pollutants. Use of RFG was required in 9 areas rated as being in severe or extreme non-attainment. Other less severe areas were allowed to choose to be in (opt into) the program. The major areas using RFG this past year were in the Northeast, the Midwest (around Chicago and Milwaukee), and Southern California.

The RFG program is being implemented in two phases, each of which contains both *prescriptive* and *performance* standards. Industry preferred performance standards, where possible, to allow some flexibility in how companies could meet the standard. The two phases target different levels of emissions reduction.

As shown in Figure FE1, Phase I targets reducing hydrocarbon emissions[1] by 15 percent during the high ozone season (summer), and reducing toxic emissions by 15 percent, or requiring fuel performance to meet the standards of a formula fuel, whichever produces the greatest reduction. In addition, Phase I requires that nitrogen oxides (NOx) not increase. Phase II has a more aggressive goal than Phase I, targeting 20 to 25 percent volatile organic compound (VOC) and toxic emission reductions. The non-performance or prescriptive requirements under both Phase I and II are shown in Figure FE2.

Phase I began in December of 1994 at the wholesale level of distribution, and was in place by January 1995 at the retail level. Within Phase I, there are two means of compliance: the simple model and the complex model. Currently, refiners are complying under what is called the "simple model," which EPA established at the end of 1991 to meet the requirements of the legislation. This "simple model" formed the guidelines for refiners from data available at that time relating fuel parameters (oxygen content, Reid vapor pressure (RVP), benzene, aromatics[2]) to emissions.

[1] Total car volatile organic compound emissions include evaporative emissions, exhaust emissions, and refueling emissions. EPA estimated that in 1990, evaporative emissions accounted for about 32 percent of the VOC emissions, exhaust emissions made up 64 percent, and refueling produced the remaining 4 percent. (Reference 1)

[2] The impact of aromatics on NOx and VOC emissions was not well understood when the simple model was developed. It was believed that aromatics would be adequately controlled through the role they play in toxic emissions. Thus, no separate maximum or cap was established for aromatics. Data is now available to quantify the effects of RVP, oxygen, benzene, aromatics, sulfur, T90, olefins, and T50. These effects have been incorporated into the complex model.

Figure FE1. Summary of RFG Performance Standards, Phase I

CAAA Legislation
1995 RFG Performance Standards

Phase I

- No increase in NOx emissions

and whichever is more stringent:

- 15 percent reduction in total car VOC emissions
- 15 percent reduction in toxic emissions

or

- Performance of formula fuel (described in legislation)

Phase II

- No increase in NOx emissions

and whichever is more stringent:

- 25 percent reduction in total car VOC emissions
- 25 percent reduction in toxic emissions
- EPA granted latitude to consider
  - technological feasibility
  - cost
- 20 percent minimum for both VOC and toxics

or

- Performance of formula fuel (described in legislation)

Other parameters such as sulfur, T90,[3] and olefins were capped at a refiner's 1990 baseline level to keep from having these parameters undercut achievements in emissions reduction from parameters being controlled in the simple model. The simple model can be used by refiners until January 1998, when the "complex model" must then be used to meet Phase I standards. (EPA issued the complex model performance standard early in 1994.)

Figure FE2. Summary of RFG Prescriptive Standards, Phases I and II

CAAA Legislation
1995 RFG Performance Standards, Phases I and II

- 2.0 weight percent oxygen minimum
- 1.0 volume percent benzene maximum
- No heavy metals
- Detergents

Phase II begins in the year 2000. During Phase II, refiners will certify RFG according to the Phase II standards using the complex model.

This article concentrates on the economics of complying with the simple model under Phase I. Table FE1 shows the RFG compliance strategies under the simple model. Refiners were given a choice of meeting requirements on an individual barrel basis, or on an average basis. As shown in Table FE1, to comply with the VOC control requirements of the CAAA, oxygen content and RVP are controlled. The simple model formula for toxics emissions is a function of fuel benzene, fuel aromatics, RVP, type of oxygenate, and oxygen content.

In addition, the regulations stipulate that for conventional gasoline:

- benzene content cannot exceed the refinery's 1990 baseline level;

- sulfur, T90 and olefins must be capped at 1.25 times a refinery's 1990 level.

The intention of these requirements is to prevent "dumping" undesirable products, such as benzene and aromatics that will be removed from RFG, into conventional gasoline.

With these guidelines, refiners determined what needed to be done to their refineries and/or crude charges to meet the specifications.

[3]The T90 point is the temperature at which 90 percent of the material is vaporized or distilled. Similarly, T50 is the temperature at which 50 percent of the material is distilled.

Table FE1. Simple Model Compliance

Objective	Approach	Averaging Standards	Per-Gallon Standards
Oxygen content	Minimum oxygen content	2.1 weight % minimum	2.0 weight % minimum
Benzene content	Maximum benzene	0.95 volume % maximum	1.0 volume % maximum
VOC	Maximum RVP specification	PSI cap Control region 1 7.1 Control region 2 8.0	PSI cap Control region 1 7.2 Control region 2 8.1
	Minimum oxygen content	2.1 weight % minimum	2.0 weight % minimum
NOx	Limit oxygen content	Cap 4.0 weight % winter 2.7 weight % summer	Cap 4.0 weight % winter 2.7 weight % summer
Toxics	Model	16.5% reduction	15.0% reduction
Sulfur		less than or equal to 1990 baseline level	less than or equal to 1990 baseline level
Olefins		less than or equal to 1990 baseline level	less than or equal to 1990 baseline level
T-90 specification		less than or equal to 1990 baseline level	less than or equal to 1990 baseline level

Source: Environmental Protection Agency, Regulation of Fuels and Fuel Additives; Standards for Reformulated and Conventional Gasoline; Final and Direct Rules, 40 CFR Part 80.

Refinery Process and Cost Impacts to Produce RFG

Refinery Processing Impacts of RFG Production

The processing patterns of U.S. refineries had to be changed to meet the "simple formula" gasoline product requirement of RFG in 1995 and the anti-dumping requirements for conventional gasoline as outlined in the prior section. The refinery operating and processing changes were made to meet three key specification changes:

- adding oxygenates to meet oxygen content requirement
- reducing RVP by removing butane from gasoline blends
- reducing benzene by a variety of process routes.

The oxygenate requirement is met by refinery production of the oxygenates methyl tertiary-butyl ether (MTBE), ethyl tertiary-butyl ether (ETBE) or tertiary amyl methyl ether (TAME) and by purchasing oxygenates, including ethanol, from merchant producers. Oxygenate addition represents a significant part of RFG's higher production cost since spot-market oxygenates have been priced 15 to 45 cents per gallon above regular gasoline at the refinery gate during 1995, and contract oxygenate prices have run considerably higher.

Reducing benzene to meet both the 1 percent maximum benzene content and the toxic standard of 15-percent reduction in exhaust benzene has been the most challenging processing problem for many refiners. Alternative processing routes to reducing benzene have been well described in a number of technical articles (References 2 through 5).

Benzene in the gasoline blending pool comes almost entirely from two components: reformate (product output from the reforming unit[4]) and fluid catalytic cracking[5] (FCC) gasoline. The FCC gasoline generally contains 0.5 to 0.8 volume percent benzene, which is within the 1 percent constraint. If a problem exists, the source of the high benzene will be the reformate component. Reformate historically represented about 35 percent of the gasoline pool (References 6,7), and when a refinery runs a moderately high benzene crude and includes the C6's[6] in the reformer charge, as was customary in pre-RFG days, the benzene content of the reformate would be 7 to 8 percent.

The refiner has two means of reducing reformate benzene. The first is to reduce reformate benzene production by eliminating the C6 cyclics (benzene and the benzene precursors methylcyclopentane and cyclohexane) from the reformer feed (naphtha). This is accomplished by pre-fractionating the naphtha (Figure FE3a). This pre-fractionated, light-straight-run stream that contains C5's and C6's can be blended directly into gasoline or can be isomerized. Isomerization[7] will both increase the stream's octane value and eliminate the benzene. The benzene and benzene precursors can also be reduced by switching to a crude oil that contains lower levels of C6 cyclics. Crude switching, however, is not always practical for refiners because of the limitation of their processing facilities.

The alternative route to meeting the benzene limit is either to remove or to convert the benzene in the reformate product. As shown in Figure FE3b, a light reformate containing benzene is separated by fractionation and then extracted to produce a salable chemical feedstock, or converted by hydrogen saturation or alkylation[8] to a gasoline blending component or petrochemical product.

Perspectives on Cost to Produce RFG[9]

There is no single cost per gallon for producing RFG, either on an absolute basis or relative to producing conventional gasoline. The cost per gallon varies for a number of reasons. The first is that the RFG cost per gallon increases as the percent of RFG in a refinery's total gasoline production increases. When RFG production is only 20 percent of total, a refiner has much greater latitude to shift components between RFG and conventional gasoline to meet the stricter RFG specifications and also to meet the anti-dumping requirements for conventional gasoline. At 50 percent RFG production, the refiner running a moderately high benzene crude will not be able to just shift components, but will need to be operating with one of the options of Figure FE3. Some refiners had to invest in additional processing facilities to accommodate this requirement.

Switching to a crude with lower C6 cyclics content may seem an easier and lower-cost solution than investment for a refiner faced with producing RFG, but refiners have limitations on the range of crudes they can process. For example, many refiners located in and serving the East Coast (PADD I refiners) have historically run West African and North Sea crudes with low sulfur and low bottoms contents.[10] These crudes also have fairly high C6 cyclics content. Large volume crudes with low C6 cyclic contents are Middle Eastern crudes, but Middle Eastern crudes have high sulfur and intermediate to high bottoms content. The high sulfur, high bottoms crudes cannot be run by the PADD I refiners having equipment sized to run West African / North Sea sweet crudes. PADD III refiners (i.e., Gulf Coast refiners), on the other hand, tend to run high sulfur, higher bottoms crudes.[11] They potentially have more flexibility to

[4] Catalytic reforming is a refining process using controlled heat and pressure with catalysts to rearrange certain hydrocarbon molecules, thereby converting paraffinic and naphthenic type hydrocarbons into a product having higher aromatic content and a higher octane number. The output is suitable for blending into finished gasoline or for use as a petrochemical feedstock.

[5] Catalytic cracking is the refining process of breaking down the larger, heavier, and more complex hydrocarbon molecules into simpler and lighter molecules. Since much of the output falls in the boiling range of gasoline, it is an effective process to increase gasoline yields.

[6] The short-hand abbreviation of C5 or C6 means any hydrocarbon molecule containing 5 carbon atoms or 6 carbon atoms respectively.

[7] Isomerization is a process that alters the fundamental arrangement of atoms in a molecule.

[8] Alkylation is a process that combines light olefins from catalytic cracking that are too low in boiling point to add to gasoline blends into larger, branched, paraffin molecules. The final product, alkylate, is blended into gasoline.

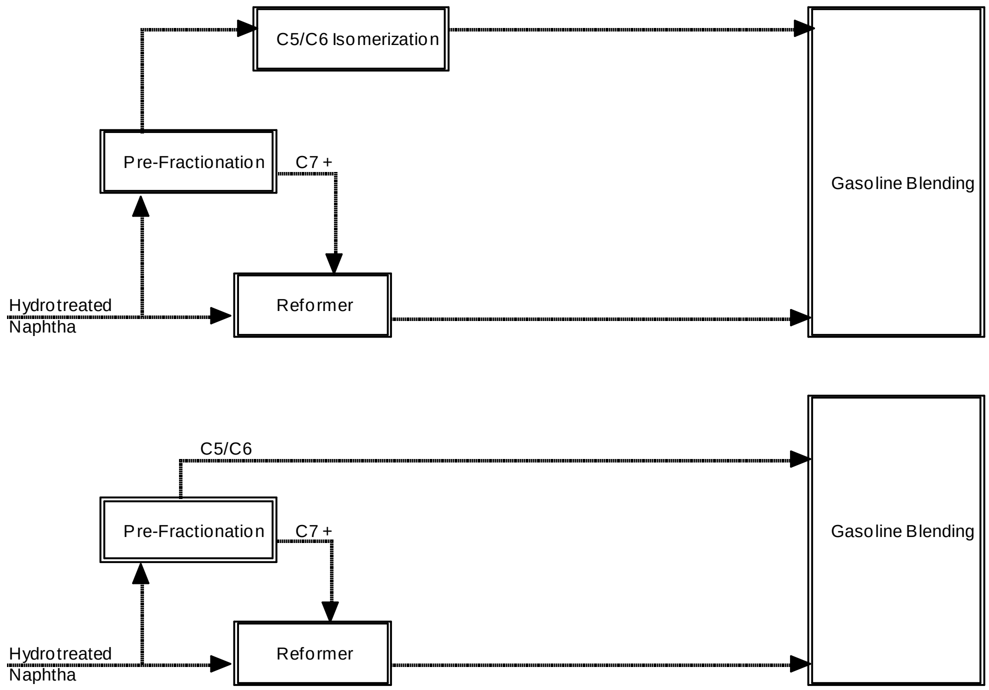
[9] Unless stated otherwise, all costs are in current dollars.

[10] Bottoms content refers to the heavy material in crude oil that boils above 1000 degrees F. The amount of this material in a barrel of crude varies across different crude types, and it is difficult to upgrade into gasoline or distillate.

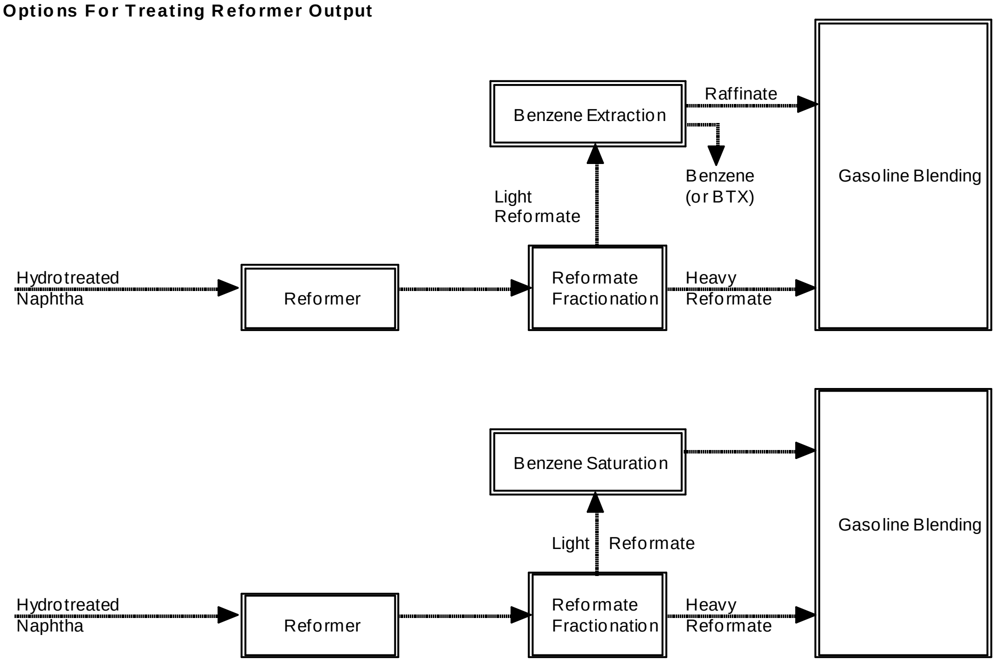
[11] A Gulf Coast refinery running high-sulfur, high-bottoms crudes would be configured differently than an East Coast refiner running light sweet crudes. For example, it would probably have more hydrotreating and coking capability than would be required by an East Coast refinery running light, sweet crudes.

Figure FE3. Reformate Benzene Reduction

a) Options For Treating Reformer Input



b) Options For Treating Reformer Output



Source: Ragsdale (Reference 2); Keeson, et al. (Reference 3).

Model Used For Cost Analysis

The analysis used a new single-refinery linear programming model. This PC model was created to analyze changes that are impacting the industry in the 1990's due to requirements to produce new reformulated fuels. The model represents crude-specific quality and yield variations of the unit streams. These stream properties are required to adequately gauge yield and cost impacts of reformulated fuels. The data base for this model contains:

- information to simulate both simple and complex refineries
- crude data for 6 crudes chosen to cover the range of crude types used by U.S. refineries
- updated cost information
- additional narrow "swing" cuts on the atmospheric vacuum unit (AVU) to reflect AVU distillation variations.

switch than the PADD I refiners, but they still have some limitations. The refiners who can move to a crude slate with lower C6 cyclic content will experience higher costs due to lower reformate yields and lower gasoline production per barrel of crude charge. Also, for refiners that can switch, moving to a lower C6 cyclic crude slate will probably not be adequate to solve the benzene problem if they are producing a high percentage of RFG.

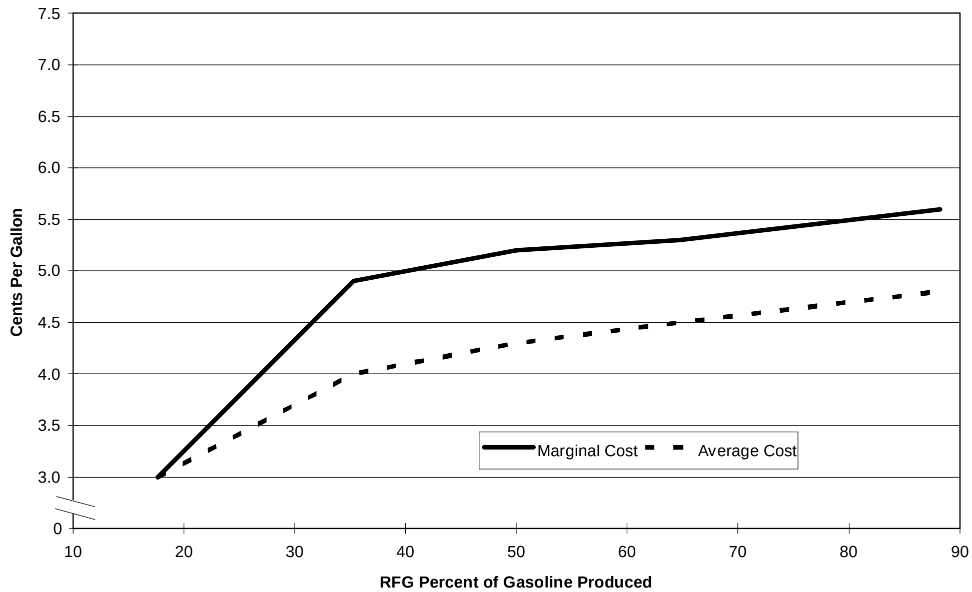
In summary, the specifications for RFG, the anti-dumping requirements for conventional gasoline, and the crude choice limitations posed by sulfur handling and downstream unit capacities have combined to leave no practical options for some refiners other than to make additional process equipment investment.

Over the past few years, many estimates of the additional cost to produce RFG have been developed that vary considerably. The most frequently cited cost for RFG production is the 1993 National Petroleum Council (NPC) study, which estimated a range of 3.0 to 7.0 cents per gallon for the increased cost to produce, deliver, and use RFG (Reference 8). In addition to the refining cost, the NPC estimated that the consumer would be impacted by increases for RFG over conventional gasoline of 2.6 cents per gallon for the cost of stationary source control, 2.5 cents per gallon for added logistics and marketing costs, and 2.5 cents per gallon for lower fuel economy. In 1994, the Energy Information Administration (EIA) combined market estimation techniques with production cost information from other sources to show a 3.9 cents-per-gallon cost increase for RFG in the summer and a 3.5 cents-per-gallon premium in the winter (Reference 9). The EIA's *Annual Energy Outlook* for 1995 estimated an RFG price premium of 4 to 6 cents per gallon over conventional gasoline sold in the Northeast (Reference 10). A "National Petroleum News" article (Reference 11) cited a Cambridge Energy Research Associates estimate that refiners' average, increased cost for producing RFG would be 11.4 cents per gallon. That 11.4 cents per gallon was broken down as 5.7 cents per gallon increased production cost plus 3.2 cents per gallon representing a 15 percent return on new facility investment plus 2.5 cents per gallon for purchased oxygenate in excess of refinery production. Seymour (Reference 12) developed an estimate based on both a review of other estimates and his own analysis and produced an estimated range of 8.2 to 11 cents per gallon for RFG production.

There are several reasons for the variation in estimates. One reason is that the cost impact of RFG production increases with the percent RFG produced. Also, cost impacts depend on the types of crudes the refinery can run and the types of process facilities in the refinery before RFG production preparations began around 1990. Another reason for variation in cost estimates is that the bases against which RFG production costs are compared are not always the same. The 1993 NPC study based its 1995 RFG production cost comparison against the cost to produce only conventional gasoline. This seems an appropriate basis, but is not the basis used in other comparisons. Differences in RFG cost estimates also occur because of the variation among analyses in the data used for process yields and qualities, and more particularly, for operating and investment costs.

Variations in cost estimates also can result from the refinery modeling methodology used. Some estimates are made using regional aggregate refineries that represent the sum of the individual units in all refineries in the region as one composite refinery. It

Figure FE4. 1995 Cost of Producing Reformulated Gasoline vs. Conventional–PADD III Sour Crude Refinery (MTBE @ $1.07)



Source: Estimates derived from EIA Refinery Model analysis.

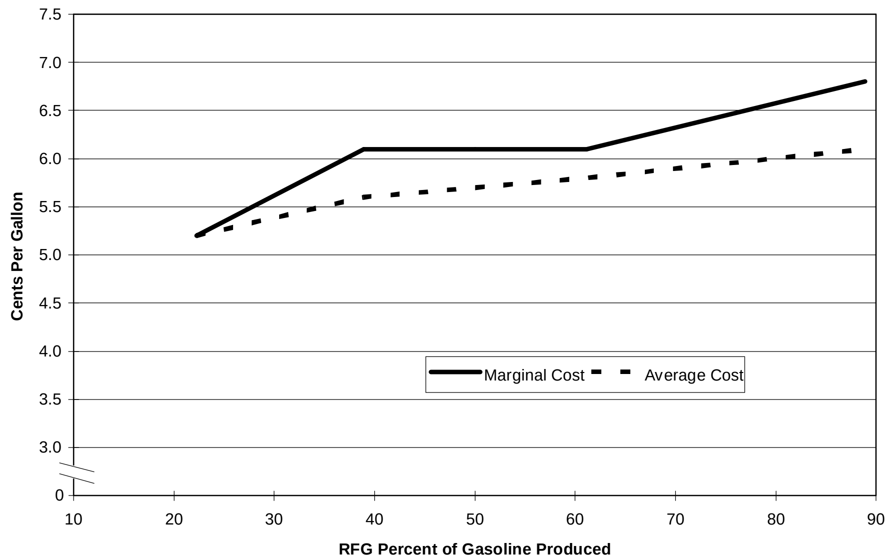
is well known by experienced refinery modelers that these aggregate refineries result in some level of *overoptimization* compared to summing together the cost effects on the collection of individual refineries, each of which has less equipment flexibility and greater crude usage limitations than the composite refinery. The concern about overoptimization (or cost underestimation) is heightened when analyzing RFG production because the increase in number of products and addition of more rigid and more numerous gasoline product specifications can produce obstacles an individual refinery must rectify, often with added equipment investment. By contrast, an aggregate refinery with some isomerization capacity, some aromatic extraction capacity, an ability to handle both the sour crudes with low C6 cyclic content as well as the sweet crudes with high C6 cyclic content may well be able to meet the stricter specifications at lower to mid-RFG production levels with no investment requirements, indicating a deceptively low cost for RFG production.

Comparison of Prices and Estimated Production Cost

This study analyzed the added cost of producing RFG gasoline in 1995 for East Coast and Gulf Coast refiners over their costs to produce only conventional gasoline (see Model sidebar). The analysis demonstrates how producing RFG impacts refiners in these areas differently. Refinery-related factors that affect RFG production costs are the:

- volume percent of RFG the refinery must produce to meet its market demand
- type of crudes the refinery can run and to which it has access
- type of processing facilities available in the refinery.

Figure FE5. 1995 Cost of Producing Reformulated Gasoline vs. Conventional–PADD I Sweet Crude Refinery (MTBE @ $1.07)



Source: Estimates derived from EIA Refinery Model analysis.

The key RFG product specifications that drive a refiner's costs are:

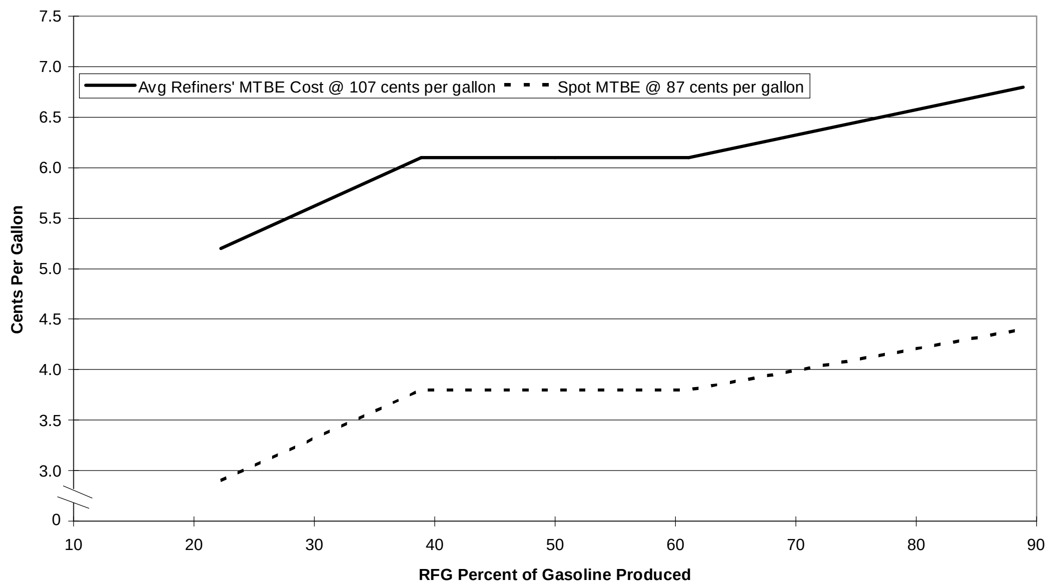
- adding the required oxygenate to increase oxygen content
- removing butane to meet reduced RVP requirements
- meeting the benzene specification on RFG.

The anti-dumping part of the regulation also requires that the benzene and aromatics in conventional gasoline (as defined by EXHAUST BENZENE equation in the simple model) do not increase over that produced by a refinery in its base year.

Some RFG-producing PADD III refiners using crudes low in C6 cyclics only experienced cost increases resulting from the increase in oxygenate and the decrease in RVP requirements. (The benzene requirement did not affect their costs.) That is, while some operational changes were made, these refiners did not have to invest in new processing equipment. Figure FE4 shows 1995 costs for a typical PADD III refinery running moderate to heavy high-sulfur crude with C6 cyclic contents in the lower range. The refinery was equipped like many PADD III refineries that run sour crudes, including: reforming, FCC, alkylation, coking, and hydrotreating for all distillation streams except the vacuum tower bottoms. When this refinery is producing only conventional gasoline, its gasoline pool is below 1-percent benzene, and a small amount of MTBE is added to enhance the octane value. Across the whole range of RFG production, meeting the 15-percent toxics reduction and the consequent benzene and aromatic content limits requires no additional changes in reformer pre-fractionation or in post-reformer, reformate fractionation processing.

In the lower RFG production percent portion of the cost curve shown in Figure FE4, the cost to produce a marginal barrel of RFG over conventional is below 5 cents per gallon. When operating in this portion of the curve, the addition of oxygenate to meet the oxygen content requirements also provides some ad-

Figure FE6. RFG Cost Sensitivity To MTBE–Sweet Crude PADD I Refinery Marginal Cost of Producing Reformulated Gasoline vs. Conventional



Source: Estimates derived from EIA Refinery Model analysis.

ditional octane to the gasoline pool, permitting reduction in reformer severity. Reducing reformer severity provides higher yields and lower reformate costs, thus canceling, to some degree, the increased cost of adding the oxygenate. When operating above 35 percent RFG, the cost to produce RFG can run over 5 cents per gallon for the *marginal barrel* of product. This cost increase results from limits placed on crude switching and on process unit constraints. Many PADD III refiners produced RFG this past year at an *average cost* of 4.0 to 4.5 cents per gallon over the cost of conventional gasoline (reflecting RFG volumes of from about 35 to 65 percent). However, some PADD III refiners faced the situation of the PADD I refiners who had to implement processing changes to meet the RFG specifications.

Areas with the highest RFG demands are California and the marketing regions of the northeast refineries located in the Delaware River Basin and in New Jersey. This northeast region is also highly dependent on crude oil imports from the North Sea and West Africa –areas where many of the crudes have high C6 cyclic content. The example of Figure FE5 is a typical PADD I refinery running Nigerian and North Sea crudes.[12] It was found to be impossible (i.e., very costly) to produce even a low level of RFG in this refinery unless additional equipment was added to reduce the benzene content. The 1995 costs shown in Figure FE5 are for a refinery to which a reformate fuel pre-fractionator and C5/C6 isomerization unit have been added. For this refinery, producing from 50 to 90 percent RFG, the *marginal cost* to produce one more barrel of RFG over the cost of conventional will be in the 6.1 to 6.8 cents-per-gallon range, and *on average*, the cost to produce RFG will fall in the 5.7 to 6.1 cents-per-gallon range.

[12] For this analysis, the PADD I refinery contained the same units as a PADD III refinery, but with less hydrotreating and coking capability. In addition, C5/C6 isomerization was added to achieve RFG benzene specifications.

Thus, for a typical PADD III refiner (who generally produced a lower percentage of RFG than a PADD I refiner), the average cost of producing RFG over conventional gasoline is 4.0 to 4.5 cents per gallon versus 5.7 to 6.1 cents per gallon for a PADD I refiner (who generally produced high percentages of RFG). These are but two examples. Some PADD III refiners experienced higher costs, and some PADD I refiners experienced both higher and lower RFG production costs than the illustrations. For example, costs can vary due to differences in oxygenate cost. A change in MTBE price of 10 cents per gallon translates to a 1.1 cent-per-gallon change in RFG production cost.

The oxygenate cost used in Figures 4 and 5 was $1.07 per gallon, which represents a blend of 50-percent contract formula price and 50 percent spot MTBE purchases over the first 8 months of 1995.[13] Contract MTBE prices ran considerably higher than spot during 1995 due to the formula arrangements locked into place by refiners when many of these contracts were signed back in 1992. To demonstrate the sensitivity of the cost to MTBE price, Figure FE6 shows the variation in cost for a PADD I refiner who is able to use all spot MTBE, which averaged 87 cents per gallon over the first 8 months of 1995 versus the $1.07 per gallon MTBE cost used in Figure FE5.

Small variations in refinery cost can represent a significant impact on refinery margins, assuming no change in product prices. For example, for a large PADD I refiner producing 200,000 barrels per day of RFG, an increase in cost of 3 cents per gallon represents a loss of over 90 million dollars per year in margin contributions.

Now we are ready to explore how these refiners fared this past year over the summer driving season. Did the resale price of RFG rise high enough over the price of resale conventional for refiners to make the same margins on RFG (or better) than on conventional?

Market Prices in the First Year

In order the explore how different types of refiners fared during 1995, the market behavior and resulting prices for gasoline are described. This section focuses on the summer driving season, which is when the price of gasoline is usually highest, and when the contribution to refiners' annual profit margin reaches its maximum.

Supply and Demand Last Spring and Summer

Price change is a reaction to crude price changes and the tightness between gasoline supply and demand, so the discussion begins by reviewing the market supply and demand for gasoline. As anticipated early in 1995, total gasoline demand during the spring and summer reached record levels, peaking at 8,243 thousand barrels per day in June (compared to the peak 8,007 thousand barrels per day in August 1994) due to continued strong economic growth (Figure FE7). RFG represented about 25 percent of that volume (close to 2,000 thousand barrels per day).

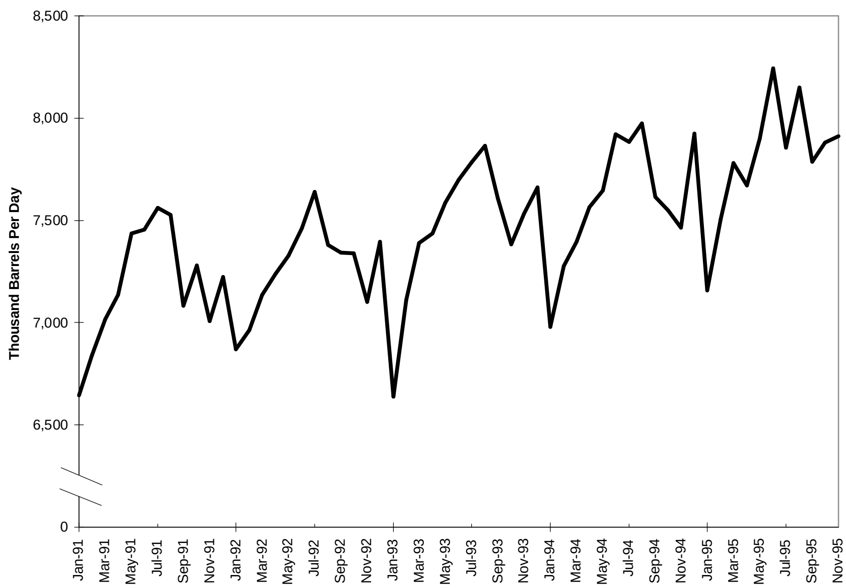
In response to the high demand, gasoline production reached record levels (Figure FE8). Had capacity reached limitations for any length of time, prices would have responded and imports would have increased.

Imports through the summer of 1995 were lower than last year, and lower than their 5 year average. This was due partially to low RFG imports (Figure FE9). Gasoline imports are mainly used in the Northeast,[14] which is the largest RFG-consuming region. RFG prices were not attractive enough on a sustained basis to result in more imports. In addition, the trade press indicated that even when prices might have been attractive to importers for a short period, RFG importers were not able to hedge their cargoes on the futures market since RFG futures contracts had inadequate volumes to be viable (Reference 13). For

[13]The formula used to estimate the contract price is based on the contract formula used by MTBE producers in 1992 when most contracts were established. It was based on n-butane, 0.34 x contract methanol price, and an additional factor to represent operating costs and profits. This last factor today is about 57 cents per gallon. Some contracts today, however, have an adjustment for spot prices that keeps them lower in price than the formula just described. While probably 70 to 75 percent of MTBE purchased in 1995 was contract, not all of it was at the high formula price. Thus, a weighting factor of 50 percent for contract and for spot price was used to estimate refiners' MTBE costs. The weights chosen are a rough approximation. (William Ludlow of DeWitt & Company provided helpful input into developing this approach.)

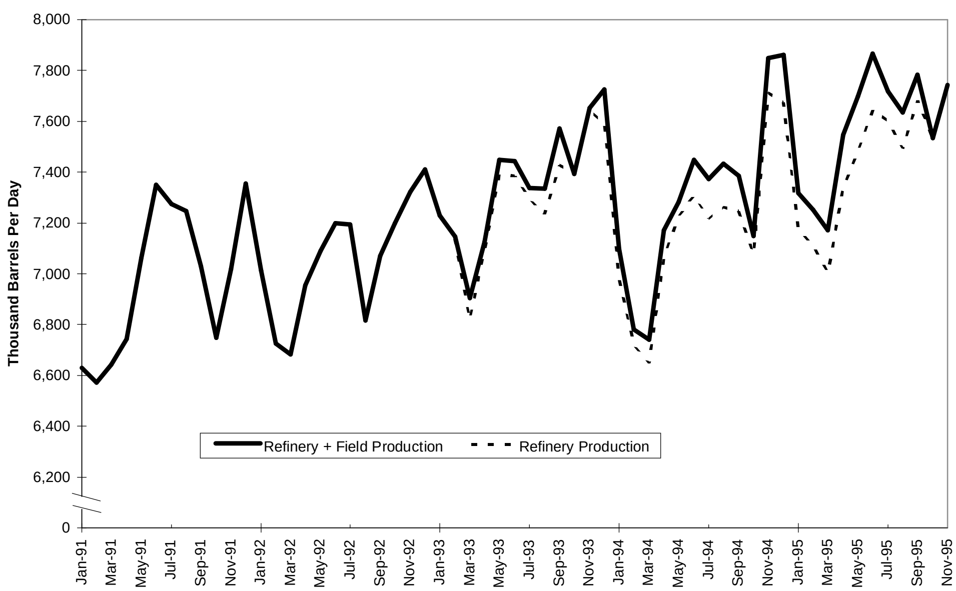
[14]In 1994, PADD I represented almost 94 percent of the finished gasoline and blending component imports in the total United States.

Figure FE7. Monthly Finished Motor Gasoline Demand, January 1991 Through November 1995



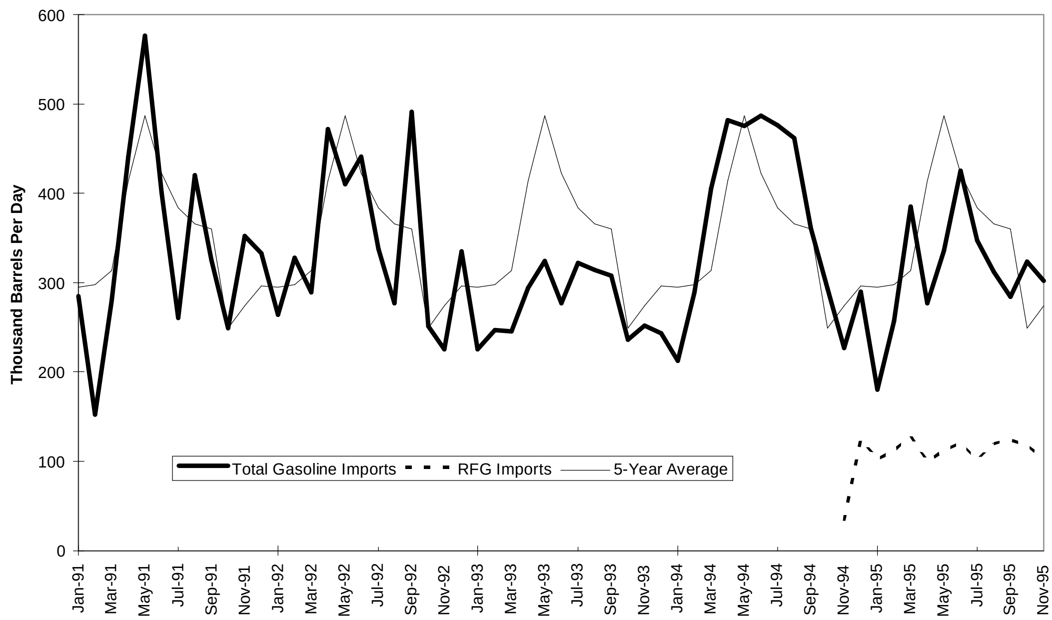
Source: Energy Information Administration, *Petroleum Supply Monthly*, various issues, Table S4; *Weekly Petroleum Status Report*, various issues, Table 14.

Figure FE8. Monthly Gasoline Production, January 1991 Through November 1995



Source: Energy Information Administration, *Petroleum Supply Monthly*, various issues, Table S4; *Weekly Petroleum Status Report*, various issues, Table 14.

Figure FE9. Monthly Gasoline and Blending Component Imports, January 1991 Through November 1995



Source: Energy Information Administration, Petroleum Supply Monthly, various issues, Table S4; Weekly Petroleum Status Report, various issues, Table 14.

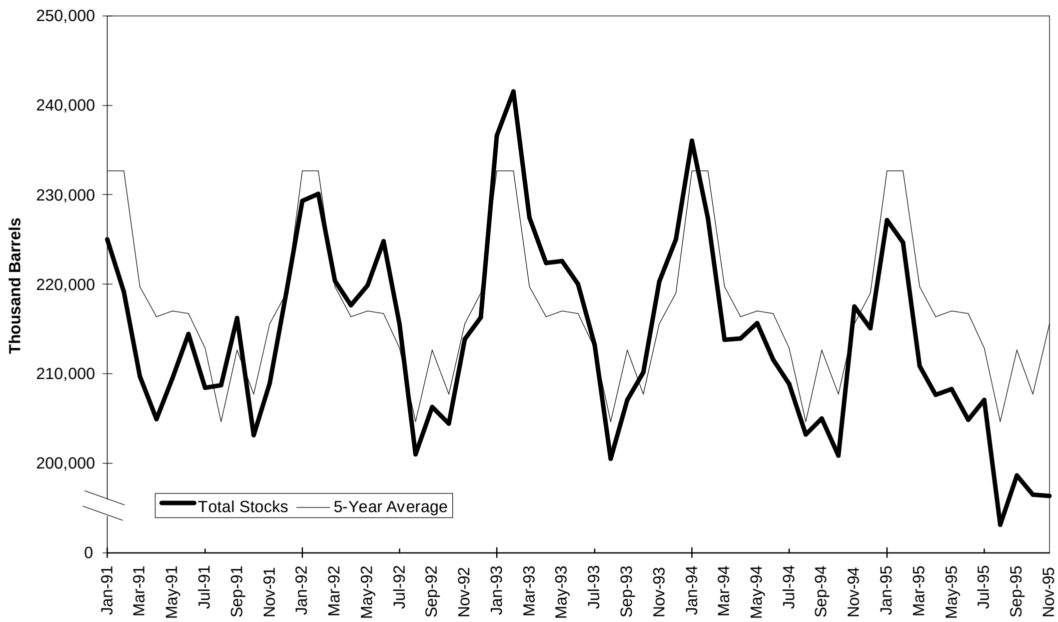
conventional gasoline, importers historically would be able to use a brief price advantage by locking in their profits with a futures contract between the time when the cargo left port and when it arrived. Without that ability, some importers were unwilling to take the risk with RFG.

As driving increased during the summer, the balance between production, imports, and demand kept stocks very low (Figure FE10). Low stocks put upward pressure on prices (Reference 14). Normally gasoline stocks would build in January[15] when gasoline demand is low, but production of gasoline continues as distillate demand is being met. This winter was warm, which resulted in more driving and thus relatively high gasoline demand in January, and correspondingly less distillate demand and production. In addition, the uncertainty over which regions would potentially withdraw from the RFG program provided a large disincentive for marketers to maintain RFG stocks.[16] Total gasoline stocks ended the winter at very low levels, raising concerns over adequacy of supply to accommodate refinery maintenance during the spring. Fortunately, no major production disruptions occurred, so the low stocks did not present any problems. RFG stocks began the year at 43 million barrels and declined to 34.5 million barrels by the end of June when driving demand had peaked. The stocks recovered to 38.0 million barrels in July, but dropped in August and September, ending September at 33.4 million barrels. Conventional stocks in April through June were at about 24 or 25 days of supply , but RFG represented only 18 or 19 days of supply, consistent with its lower days-supply pattern since its startup in December.

[15] January demand is usually low, but refiners still produce gasoline as a co-product while meeting winter high distillate demands. Thus stocks normally build during this time.

[16] A marketer with RFG stocks located in a region that withdraws from the program will likely end up selling the RFG stocks at lower conventional gasoline prices.

Figure FE10. Gasoline and Blending Component Stocks (End of Month), January 1991 Through November 1995



Source: Energy Information Administration, Petroleum Supply Monthly, various issues, Table S4; Weekly Petroleum Status Report, various issues, Table 14.

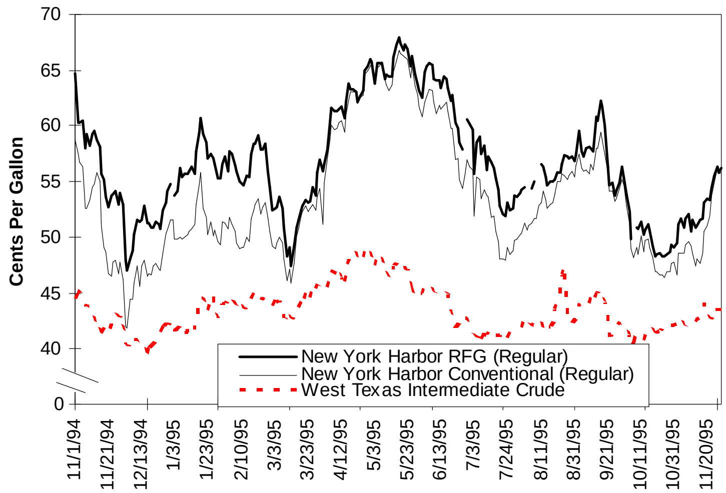
Gasoline Wholesale/Spot Prices

The prior discussion of RFG costs focused on the difference in cost to produce RFG over conventional gasoline. In the long term, one would expect prices on average to reflect these cost differences. However in the short term, other supply and demand factors can cause the margin between RFG and conventional prices to vary both above and below costs at any point in time. Before exploring the price difference between RFG and conventional gasoline, the absolute price behavior needs to be analyzed. If the underlying prices are showing much volatility, the differences between RFG and conventional may also be fluctuating significantly as the market seeks equilibrium.

Spot prices fluctuated considerably over the 1995 gasoline season. Figure FE11 shows both spot RFG and conventional regular gasoline prices since the start of the RFG program in 1994. Figure FE12 shows the spot price spreads of conventional and RFG regular gasolines over the spot price of West Texas Intermediate Crude Oil. Price spreads highlight the variation in the product market prices apart from crude price variations. (Crude represents about 75 percent of the resale price of gasoline, and therefore, a 1 cent-per-gallon change in the price of crude oil normally results in about the same change in the price of gasoline.)

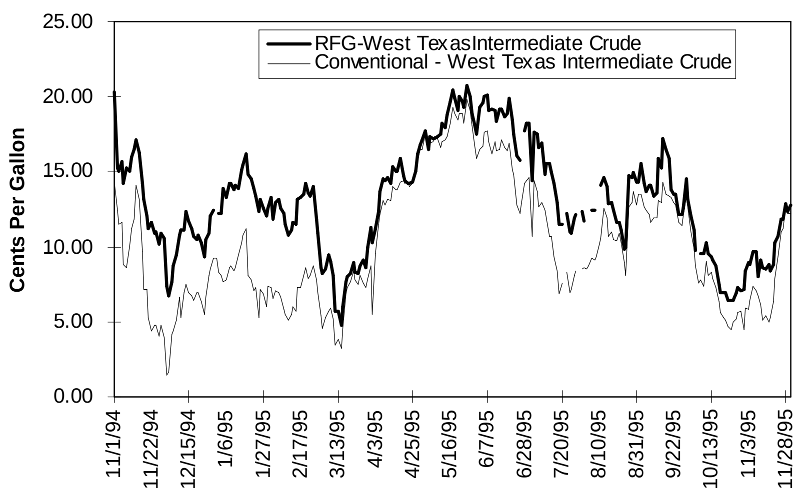
Going back to the introduction of RFG, the price spreads over crude price of both conventional gasoline and RFG fell in early December, 1994, as the market eased in light of opt-outs reducing the need for RFG, and of a smooth beginning to the RFG program at the wholesale level. Prices usually remain weak through the winter months due to low demand (relative to the summer months) and excess production of gasoline that results from refiners producing heating fuel for the cold weather. The expected spring gasoline price run up did not occur in 1995 until mid March, when refinery turnarounds and low stocks increased upward price pressure.

Figure FE11. RFG, Conventional Gasoline, and Crude Oil Daily Spot Prices, November 1994 Through November 1995



Source: Reuters Information Services.

Figure FE12. New York Harbor Regular Gasoline Spreads (Daily Spot Prices), November 1994 Through November 1995



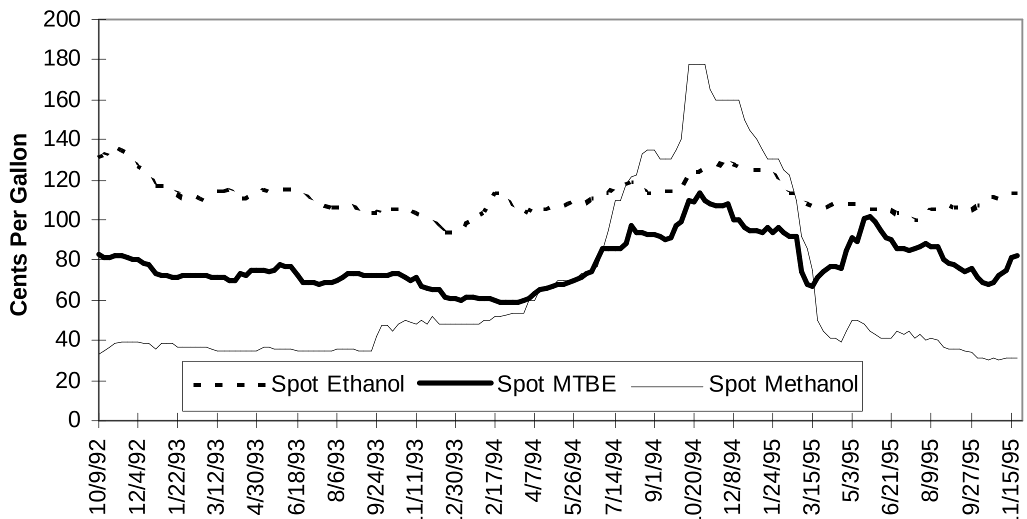
Source: Reuters Information Services.

Oxygenates Impact on Gasoline Prices

The advent of RFG increased the role of oxygenate prices in the price of gasoline. Recall that RFG requires 2.0 weight percent oxygen during the summer for all ozone non-attainment areas, and 2.7 weight percent during the winter in carbon monoxide non-attainment areas. As discussed earlier, the addition of oxygenates to RFG produces a large part of the cost increase of RFG over conventional gasoline. Prior to the Clean Air Act Amendments of 1990, oxygenates were used primarily as octane enhancers. The use of oxygenated gasoline, which began nationally in the fall/winter of 1992, increased the need for oxygenates -- but on a highly seasonal basis. Oxygenated gasolines were only required during the winter months -- in most cases November through February. RFG has now increased the need for oxygenates year round; although, some seasonal increase during the winter is still required to control carbon monoxide emissions.

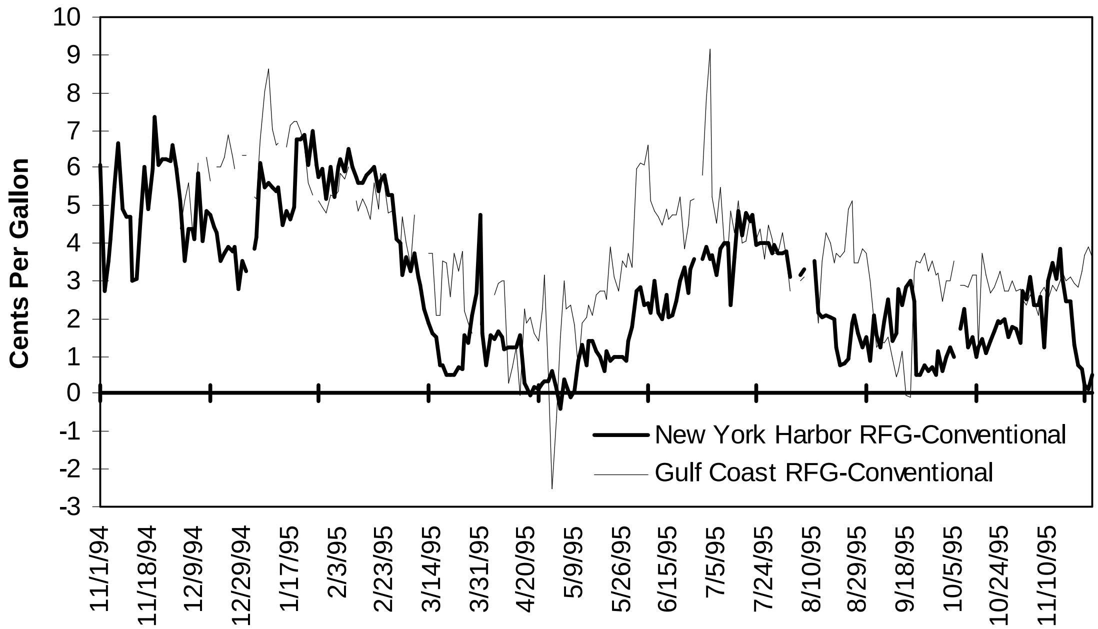
Spot MTBE prices showed dramatic swings since the beginning of the RFG program last fall (Figure FE13). Several production problems with methanol plants and uncertainty over the amount of MTBE needed for last winter caused both methanol and MTBE prices to increase considerably in October as refineries began producing oxygenated gasoline and RFG. MTBE peaked at $1.10 in mid October, but began falling off as supplies appeared to be adequate. Shortly after the opt-outs were announced in early December, prices moved under $1.00 per gallon, but stayed over 90 cents per gallon until the end of the oxygenated gasoline season in March, when prices plummeted to less than 70 cents per gallon. By that time, the market perceived not only a decrease in demand, but also an excess of production capacity. MTBE prices stopped their decline sooner than did methanol prices. MTBE prices were buoyed by MTBE's use in gasoline as gasoline prices started their spring increase. Spot MTBE prices peaked at over $1.00 per gallon in conjunction with gasoline prices, and dropped back almost to 70 cents per gallon during September.

Figure FE13. Oxygenate Spot Prices, Week Ending October 9, 1992 Through November 22, 1995



Source: *Octane Week*, various issues.

Figure FE14. Regular RFG minus Conventional Gasoline Daily Spot Prices, November 1994 Through November 1995



Source: Reuters Information Services.

Prices and price spreads finally peaked in the second half of May and began to fall as refinery turnarounds were finished and demand for the season was better known. Prices fell through June until the second half of July. Continued low stocks and a variety of refinery problems had accumulated to tighten prices slightly as the peak vacation month of August got underway. Hurricane Erin also created some additional pressure as a number of refineries had to reduce production in preparation for the oncoming hurricane. By mid August, refinery recoveries and the return of output from those refineries that had pulled back as a result of the hurricane caused prices to relax relative to crude price. However, crude price increased strongly the second half of August, driving gasoline prices higher. As September unfolded and the peak driving season began to wind down, the gasoline price spread remained fairly constant.

RFG Premium Over Conventional Gasoline

The fluctuations in spot gasoline price spreads over crude were an indication of the fluctuations in RFG price over conventional prices. If the spot prices reflected only costs, one would have expected the New York Harbor RFG price premium over conventional to be in the 6.1 to 6.8 cents-per-gallon range. As discussed earlier, a large part of the RFG price premium is due to oxygenate costs. Thus, one might also expect to see some variation due to variation in prices of oxygenates. (See Oxygenates Sidebar)

Figure FE14 shows the difference between RFG and conventional regular gasoline prices. As the program began in early December, the announcement by Pennsylvania to withdraw from the program followed by selected counties in New York and Maine weakened RFG prices, bringing the New York Harbor spot differential down to about 3 cents per gallon by January. However, as low stocks and high demand persisted, the differential increased and hovered around the 5.5 cents per gallon through early February, consistent with the high oxygenated prices and marginal production cost estimates. As the oxygenated gasoline season came to an end, the markets relaxed, and both MTBE prices and RFG premium relative to conventional gasoline began to fall. But falling MTBE prices could not completely explain the drop in New York Harbor RFG premium to less than 1 cent per gallon by the second half of March. During this same time, both New Jersey and Wisconsin were considering suspending RFG until health effects of oxygenates, particularly MTBE, could be more fully understood. Continuing demand uncertainty along with falling MTBE prices seemed to be behind the plunge in the spot RFG premiums.

With the exception of a few days in late March, from mid March to June, the New York Harbor spot RFG price premium hovered at 1 cent per gallon or lower. Gulf Coast premiums were slightly better, but varied more. Neither the Gulf Coast nor the Northeast saw spot premiums for RFG near the 4 cents per gallon level until July. This premium fell again in the Northeast in August, but held in the Gulf Coast.

Neither oxygenate prices nor RFG supply, which remained relatively tight, could explain the low RFG premiums through early June, or the subsequent drop in premiums again in August. The answer lay on the other side of the difference equation -- conventional gasoline. Both during the March-June period and in the Northeast during August, the RFG-conventional price difference fell because concerns arose over the availability of conventional gasoline, thereby strengthening conventional prices relative to RFG. In particular, in the second half of April, the differential was lowest when refiners were forced to cut conventional output to make room for the summer grades. The trade press reported that many refiners purchased conventional on the spot market during this time, driving conventional prices higher. (Figure FE9 shows that imports picked up slightly in May and June in response to the higher prices, but dropped back as prices weakened.)

Table FE2. PADD IB Price Premiums for RFG (RFG Price - Conventional Price) vs. Refiners' RFG Cost Increase over Conventional Gasoline
(Cents Per Gallon)

	New York Harbor Average Spot RFG minus Conventional Price Difference (1)	EIA PADD IB Average Rack RFG minus Conventional Price Difference	PADD 1 Refiners' Marginal RFG minus Conventional Cost Difference (2)	PADD 1 Refiners' Average RFG minus Conventional Cost Difference	Estimated Refiners' MTBE Cost (3)
January, February	5.6	6.6	7.8-8.6	7.4-7.8	122.3
March, April, May	1.3	3.3	5.7-6.4	5.3-5.7	103.5
June, July, August	2.9	2.8	5.5-6.2	5.1-5.5	101.7
8-Month Average	2.9	3.9	6.1-6.8	5.7-6.1	107.1

Notes: (1) Averages shown are simple averages of daily New York Harbor regular RFG minus regular conventional prices in the case of spot prices, and simple averages of the monthly RFG regular rack minus regular conventional rack prices in the case of the rack prices. (2) PADD I refiners costs are based on RFG production ranging from 50 to 90 percent RFG. (3) Refiners' MTBE cost is estimated as a combination of 50 percent formula contract MTBE price and 50 percent spot price. The formula contract price in cents per gallon was estimated as n-butane spot price + .34 x methanol contract price + 57. While probably 70 to 75 percent of the MTBE purchased in 1995 was contract, not all contracts were sold at the formula price used in the calculation. Some included an adjustment for spot prices, which would lower the contract price from the given formula. Thus, the 50-percent weight was used rather than 70-percent to reflect the lower contract prices.

Source: Spot Prices: Reuter Information Services. Rack Prices: Energy Information Administration, *Petroleum Marketing Monthly*, 1995, various issues, Tables 32 and 34.

Table FE3. PADD III Price Premiums for RFG (RFG Price - Conventional Price) vs. Refiners' RFG Cost Increase over Conventional Gasoline
(Cents Per Gallon)

	Gulf Coast Average Spot RFG minus Conventional Price Difference (1)	EIA PADD III Rack RFG minus Conventional Price Difference	PADD III Refiners' Marginal RFG minus Conventional Cost Difference	PADD III Refiners' Average RFG minus Conventional Cost Difference (2)	Estimated Refiners' MTBE Cost (3)
January, February	5.8	4.8	6.8-7.0	5.7-6.2	122.3
March, April, May	2.5	1.6	4.5-4.9	3.6-4.1	103.5
June, July, August	4.5	2.3	4.3-4.7	3.4-3.9	101.7
8-Month Average	4.0	2.6	4.9-5.3	4.0-4.5	107.1

Notes: (1) Averages shown are simple averages of daily Gulf Coast RFG minus regular conventional prices in the case of spot prices, and simple averages of the monthly RFG regular rack minus regular conventional rack prices in the case of the rack prices. (2) PADD III refiners' costs are based on RFG production ranging from 35 to 65 percent RFG. (3) Refiners' MTBE cost is estimated as a combination of 50 percent formula contract MTBE price and 50 percent spot price. The formula contract price in cents per gallon was estimated as n-butane spot price + .34 x methanol contract price + 57. While probably 70 to 75 percent of the MTBE purchased in 1995 was contract, not all contracts were sold at the formula price used in the calculation. Some included an adjustment for spot prices, which would lower the contract price from the given formula. Thus, the 50-percent weight was used rather than 70-percent to reflect the lower contract prices.

Sources: Spot prices: Reuter Information Services; rack prices: Energy Information Administration, *Petroleum Marketing Monthly*, 1995, various issues, Tables 32 and 34.

Conclusion

To look at how well RFG refiners did versus conventional gasoline refiners, we compare the wholesale market price differences in different months to the additional costs needed to produce the product. Table FE2 summarizes the difference between RFG and conventional (regular grade) prices in the PADD IB areas this past summer season, and shows PADD I refiners' costs to produce a barrel of RFG over that of conventional. Table FE3 shows similar information for PADD III.

The tables show price premiums for RFG over conventional both in the spot market and from the rack prices reported to EIA. While spot prices tend to fluctuate more than the EIA prices, both price series present a measure of price premium in the wholesale markets. The tables also show the refiners' marginal cost to produce RFG over conventional and their average costs. Using either cost measure, refiners in PADDs I and III would have done better making conventional gasoline than RFG.

References

1. Mike Kulakowski, Texaco Refining and Marketing, "Reformulated Gasoline, Defining the Challenge," Proceedings Published from *Symposium and Tutorial on Impact of Reformulated Fuels*, 208th National Meeting, American Chemical Society (Washington, DC, August 21-26, 1994), pp 494-497.

2. Ralph Ragsdale, "U.S. Refiners Choosing Variety of Routes to Produce Clean Fuels," *Oil and Gas Journal* (Tulsa, OK, March 21, 1994), pp. 51-57.

3. William H. Keeson, et al, "Benzene Reduction Alternatives," Annual Meeting National Petroleum Refiners' Association, Paper: AM91-36 (San Francisco, CA, March 1991).

4. Jeffrey G. Grant and Richard A. Pourciau, Star Enterprise, "Gasoline Reformulation, Fractionate, Innovate, & Reformulate," *Fuel Reformulation* (Denver, CO, January / February 1992), pp. 18-25.

5. Alan R. Goelzer, et al, "Refiners Have Several Options for Reducing Gasoline Benzene," *Oil and Gas Journal* (Tulsa, OK, September 13, 1993), pp. 63-69.

6. George H. Unzelman, "Ethers Will Play Larger Role in Octane, Environmental Specs for Gasoline Blends," *Oil and Gas Journal* (Tulsa, OK, April 17, 1989), pp. 44-49.

7. UOP, *The Challenge of Reformulated Gasoline*, (Copyright 1994 by UOP).

8. National Petroleum Council, *U.S. Petroleum Refining*, Volume I (Washington, DC, August 1993), p. 34.

9.Tancred Lidderdale, "Demand, Supply, and Price Outlook for Reformualted Motor Gasoline 1995," *Monthly Energy Review*, Energy Information Administration (Washington, DC, July 1994), pp. 1-10.

10. *Annual Energy Outlook 1995*, Energy Information Administration (Washington, DC, January 1995), p. 47.

11. Mark Edmond, "Refinery Crisis: What It Means to Oil Marketers," National Petroleum News, (Arlington Heights, IL, April 1992) pp. 28-34.

12. Adam Seymour, Oxford Institute for Energy Studies, *Refining and Reformulation: The Challenge of Green Motor Fuels*, (Oxford, U.K., 1992) pp. 54-55.

13. "WTO To Review RFG Dispute," *Octane Week*, (Potomac, MD, April 17, 1995), p. 8.

14. John Zyren, "What Drives Motor Gasoline Prices?, *Petroleum Marketing Monthly*, Energy Information Administration (Washington, D.C., June, 1995), pp. xiii-xxv.