Demand and Price Outlook for Phase 2 Reformulated Gasoline, 2000

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Summary

Congress last enacted major amendments to the Clean Air Act in 1990 (CAA90). The CAA90 (Public Law 101-549) includes programs to control acid rain and reduce damage to the stratospheric ozone layer, new standards for emissions of hazardous air pollutants, and new requirements for motor vehicles and fuels. The amendments and earlier provisions of the Clean Air Act appear to have contributed to significant improvements in air quality nationwide. For example, peak ozone concentrations have declined 30 percent between 1978 and 1997; the 1997 average ambient concentration of carbon monoxide is 60 percent lower than it was in 1978; and annual mean nitrogen dioxide concentrations have decreased in urban areas by 25 percent since 1978.[2]

The reformulated motor gasoline (RFG) provisions of CAA90 require reductions in automobile emissions of ozone-forming volatile organic compounds during the summer high-ozone season, and of toxic air pollutants and nitrogen oxides during the entire year in certain areas of the United States. Phase 2 of the RFG program will begin on January 1, 2000.

This article presents projections of demand and the market price premium for Phase 2 RFG in the year 2000. The projections in this article are based on forecasts in the *Short-Term Energy Outlook*, which is published monthly by the Energy Information Administration.

Demand for Phase 2 RFG is expected to represent about 34 percent of total motor gasoline demand in 2000. Demand projections are based on estimated populations of the participating ozone nonattainment areas and per capita motor gasoline demand in each area.

Refineries will have to change operating procedures, make plant modifications, and obtain new process equipment in order to meet the new emissions reduction requirements for Phase 2 RFG. The higher costs of production are expected to yield the following wholesale price premiums (in cents per gallon of gasoline) for Phase 2 RFG above the price of conventional motor gasoline:

	Southern States (EPA region 1)	Northern States (EPA region 2)
Summer (May 1 - September 15)	3.5	4.0
Winter (September 16 - April 30)	2.5	2.5

These projected price premiums may fluctuate by as much as 1 cent per gallon depending on the market price of oxygenates (e.g., fuel ethanol and MTBE).

Additional costs to store, transport, and distribute RFG are not expected as Phase 2 RFG works its way through the system replacing Phase 1 RFG. If the current trend requiring specific gasolines in limited areas continues, though, local spikes in retail prices could become more routine.

The use of oxygenates, which have a lower energy content than the motor gasoline components they displace, raises consumers' effective final costs by 0.5 to 1.5 percent as a result of reduced fuel economy (i.e., miles per gallon).

Introduction

The Clean Air Act requires that all areas of the country meet National Ambient Air Quality Standards (NAAQS), which are set by EPA at levels that are expected to be protective of human health and the environment. The Federal law requires that States do not exceed these standards. Areas that do exceed the NAAQS are required to develop and implement plans to attain them.

NAAQS have been established for 6 "criteria" air pollutants: ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, particulate matter, and lead. Air toxics (e.g., benzene, butadiene, formaldehyde, acetaldehyde, and polycyclic organic matter) is another set of pollutants regulated under the Clean Air Act. Ozone is the only air pollutant that is not directly emitted into the air but is the result of a reaction of volatile organic compounds and nitrogen oxides, which are both emitted by stationary and mobile sources.[(3)]

The U.S. petroleum refining industry has responded to 5 major new Federal rules on motor gasoline product quality in the last 11 years:

Environmental Regulations Affecting the Product Quality of U.S. Motor Gasoline	
Phase 1 Summer Volatility (RVP) Regulation	June 1989
Phase 2 Summer Volatility (RVP) Regulation	May 1992
Oxygenated Gasoline	November 1992
Reformulated Gasoline Phase 1	December 1994
Reformulated Gasoline Phase 2	January 2000

The Phase 2 reformulated gasoline (RFG) standards consist of 2 fuel specifications (maximum benzene content and minimum oxygen content) and 3 performance standards applying to automobile emissions of volatile organic compounds (VOC) during the summer months and nitrogen oxides (NOx) and toxic air pollutants (TAP) year-round (Table 1). The emissions reduction performance standards are measured by use of a mathematical model that relates each type of emission to specific fuel components. The emissions reductions are measured relative to the average gasoline produced in 1990 (the "baseline gasoline"). The application of an emissions model provides refiners some flexibility in producing gasoline to meet the emissions reduction performance standards.

Phase 1 of the RFG program required refineries to begin production of RFG on December 1, 1994, using the *simple emissions model*, which judged emissions compliance by use of 4 gasoline variables (Reid vapor pressure, oxygen, benzene, and total aromatics). In January 1998, refiners were required to switch to the *Phase 1 complex emissions model*, which introduced 4 additional variables (sulfur, olefins, and 2 distillation limitations). Phase 2 of the RFG program will apply to all RFG in the distribution system beginning January 1, 2000. The *Phase 2 complex emissions model* uses the same variables as the Phase 1 complex emissions model. However, the estimated emissions using the Phase 2 model are different from those predicted by the Phase 1 model.

The VOC, NOx, and TAP emissions reduction performance standards under Phase 1 using the Phase 1 complex emissions model and under Phase 2 using the Phase 2 complex emissions model are not directly comparable because of the differences between the Phase 1 and Phase 2 complex emissions models. An approximate comparison is provided in Table 1, which estimates emissions of a fuel that complies with Phase 1 requirements but uses the Phase 2 complex emissions model. The comparison indicates that Phase 1 winter RFG comes very close to meeting the Phase 2 winter emissions reduction requirements for TAP and NOx. In fact, the average quality RFG produced during the 1997 - 1998 winter (December 1997 through February 1998) already met the Phase 2 RFG requirements (this is described in more detail later in this report). The difficult task facing refiners is meeting the required additional reductions in VOC and NOx during the summer months. The additional Phase 2 reduction in summer TAP emissions is small, and is also already being met by refiners.

Table 1. Reformulated Gasoline Averaging Standards

	RFG Phase 1 January 1995 - December 1999			RFG Phase 2 January 2000		
	Summer Region 1	Summer Region 2	Winter	Summer Region 1	Summer Region 2	Winter
Product Quality Standards:						
Oxygen, weight % min	2.1	2.1	2.1	2.1	2.1	2.1
Benzene, volume % max	0.95	0.95	0.95	0.95	0.95	0.95
Performance Standards (using Phase 2 complex emissions model), percent reduction required:						
Toxic Air Pollutants	18.5 %	17.8 %	17.3 %	21.5 %	21.5 %	21.5 %
Volatile Organic Compounds	20.8 %	10.5 %	n.a.	29.0 %	27.4 %	n.a.
Nitrogen Oxides	1.4 %	1.6 %	1.7 %	6.8 %	6.8 %	1.5 %

n.a. - not applicable

Notes:

- Region 1 (southern States) - AL, AZ, AR, CA, CO, DC, FL, GA, KS, LA, MD, MS, MO, NV, NM, NC, OK, OR, SC, TN, TX, UT, and VA.
- Region 2 (northern States) - CT, DE, ID, IL, IN, IA, KY, ME, MA, MI, MN, MT, NE, NH, NJ, NY, ND, OH, PA, RI, SD, VT, WA, WV, WI, and WY.
- Summer - May 1 through September 15; Winter - September 16 through April 30.
- Performance standards for Phase 1 RFG are calculated by using Phase 2 complex emissions model. Average levels for olefins, E200, E300, and summer aromatics are fixed at 1990 gasoline baseline. Summer RVP for region 1 (7.1 psi) and region 2 (8.0 psi) are fixed to meet Phase 1 complex emissions model VOC emissions reductions of 36.6 percent and 17.1 for regions 1 and 2, respectively. Sulfur (300 ppm) and winter aromatics (24.3 volume percent) are fixed to meet Phase 1 complex emissions model requirements for average 16.5 percent toxics and 1.5 percent nitrogen oxides emissions reductions. These levels are comparable to the EPA's estimate of Phase 1 fuel composition in the *Final Regulatory Impact Analysis for Reformulated Gasoline* (Washington, DC, December 13, 1993), Table V-6.

Source: Code of Federal Regulations, Title 40, Part 80, "Regulation of Fuels and Fuel Additives."

Reformulated Gasoline Demand

Forecasting reformulated gasoline demand in the year 2000 is not difficult because we have over 4 years of history of RFG sales on which to base our forecasts. What can change, however, is the number of areas participating in the program. For example, beginning June 1, 1999, St. Louis, Missouri, will join the list of control areas requiring RFG.[4] The purpose of this demand analysis is to evaluate the conventional method for estimating RFG demand in specific control areas.

Refer to the EIA analysis article "Areas Participating in the Reformulated Gasoline Program," for a list of cities that participate in the reformulated gasoline program. This article is available online at:

- http://www.eia.gov/emeu/steo/pub/special/pdf/rfg2.pdf

This article includes:

- A list of all control areas, their populations, dates of opt-in or opt-out, and an Excel spreadsheet with control area populations at the county level.
- References to all opt-in and opt-out notices published by the Environmental Protection Agency in the *Federal Register* with pointers to their Internet addresses where available.
- History of Environmental Protection Agency opt-in and opt-out regulations.

RFG market shares for each State (State RFG demand as a percentage of total State motor gasoline demand) are assumed to be equal to the proportion of a State's population that resides within an RFG control area.

State RFG Market Share =	Each State's estimated control area population divided by the total State population

RFG demand forecasts are then based on the estimated State RFG market shares and the projected total State motor gasoline demands.

State RFG Demand =	State's RFG market share multiplied by the State's total motor gasoline demand

RFG market shares are estimated at the State level because of significant differences in per capita demands across States. In general, States with a higher proportion of residents in metropolitan or urban areas have lower per capita gasoline demands.[(5)] For example, per capita demand in 1997 ranged from a low of 309 gallons per person per year in New York with 91.7 percent of its population living in metropolitan areas to 683 in Wyoming with a 29.8 percent metropolitan population.[(6)] Since RFG control areas are primarily metropolitan areas, estimating RFG demand at a more aggregate level will bias RFG demand estimates upwards.

In the tables that follow, the control area population of a region (2 or more States) may not equal that region's estimated RFG market share because of the differences in per capita demands across States. RFG market share for a region is based on the estimated RFG demand and total gasoline demand for each State within the region.

Regional RFG Market Shares = The sum of RFG demand for each State in a region, divided by the sum of each State's total gasoline demand.

Table 2. Predicted Reformulated Gasoline Market Shares by Petroleum Administration for Defense District (PADD), Year 2000

Region	Control Area Population July 1, 1996 (thousands)	Region Population July 1, 1996 (thousands)	Predicted RFG Market Share from State Control Area Population Shares (percent)
PADD 1A - New England	11,051	13,351	79.2 %
PADD 1B - Central Atlantic	29,340	44,568	67.2 %
PADD 1C - Lower Atlantic	3,972	41,276	9.5 %
PADD 2 - Midwest	13,026	74,587	16.0 %
PADD 3 - Gulf Coast	8,280	34,691	23.0 %
PADD 4 - Rocky Mountain	0	8,373	0 %
PADD 5 - West Coast	34,490	48,437	67.1 %
Total U.S., 2000	**100,159**	**265,284**	**34.1 %**

Notes: Includes St. Louis, Missouri, opt in, and Maine opt out, and State reformulated gasoline programs in northern California and Phoenix, AZ. PADD and U.S. predicted RFG market shares do not correspond to control area population shares because of differences in per capita demands across States. Regional RFG market shares estimated from State control area population shares and State per capita gasoline demand based on 1997 State total motor gasoline demand.

Sources: State total motor gasoline demand: Federal Highway Administration, "Monthly Gasoline Reported by States," *Highway Statistics 1997*, FHWA-PL-98-020 (Washington, DC, Nov. 1, 1998), Table MF-33GA. Population: U.S. Census Bureau.

We can evaluate the accuracy of this RFG market share estimation methodology by comparing estimated with actual RFG market shares reported by EIA. Estimated State RFG market shares are calculated by using control area population shares and State total gasoline demand data reported by the Federal Highway Administration (FHWA), as described above. Although FHWA does not report gasoline sales by type, e.g., RFG versus conventional gasoline, State RFG market shares are available from EIA statistics. However, a State-by-State comparison is complicated because FHWA State gasoline demands do not necessarily correspond to EIA State demands.[(7)] Where differences do occur between FHWA and EIA State demand data, they are often offsetting between neighboring states. For example, EIA reports higher deliveries to Maine but lower sales in New Hampshire; higher in New Jersey and lower in New York; higher in California but lower in Arizona. Consequently, a comparison of estimated RFG market shares to actual market shares should be done on a regional level.

The comparison of estimated regional RFG market shares to actual RFG market shares reveals differences of less than 1.5 percent at the regional level and 0.2 percent at the national level (Table 3). Two significant corrections were made to the estimated RFG market shares in the analysis. The estimated RFG market shares for New York City and Chicago were multiplied by 0.85 to yield reasonable comparisons at the State and sub-PADD levels.

Table 3. Comparison of Estimated RFG Market Shares With Actual RFG Market Shares by Petroleum Administration for Defense District (PADD), 1997
(percent of total gasoline demand)

Region	Estimated 1997 RFG Market Share	Actual 1997 RFG Market Share
PADD 1A - New England	85.9 %	87.1 %
PADD 1B - Central Atlantic	64.2 %	62.6 %
PADD 1C - Lower Atlantic	9.5 %	9.3 %
PADD 2 - Midwest	11.8 %	11.3 %
PADD 3 - Gulf Coast	23.0 %	23.2 %
PADD 4 - Rocky Mountain	0 %	0 %
PADD 5 - West Coast	67.1 %	67.1 %
Total U.S., 1997	**32.8 %**	**32.6 %**

Notes: Estimated RFG market shares for New York City and Chicago are corrected by multiplying control area population shares by 0.85. Phoenix, Arizona, participation began in July 1997.

Sources: Estimated RFG market shares based on July 1, 1996, populations and total gasoline sales reported by Federal Highway Administration, "Monthly Gasoline Reported by States," *Highway Statistics 1997*, FHWA-PL-98-020 (Washington, DC, November 1, 998), Table MF-33GA. Actual 1997 RFG market share: Energy Information Administration, "Prime Supplier Sales Volume of Motor Gasoline," *Petroleum Marketing Annual 1997*, DOE/EIA-0487(97) (Washington, DC, December 1998), Table 48.

There are several possible explanations for these differences between estimated and actual State RFG market shares.

1997 estimated RFG market share larger than actual:

- RFG control areas are generally metropolitan areas, which have lower per capita gasoline demands than non-metropolitan areas.
- Delivery and sale of conventional gasoline within RFG control areas (i.e., noncompliance).
- Reported delivery of conventional gasoline in one State (region) was actually sold in another State (region).

1997 estimated RFG market share smaller than actual:

- A 1 to 2 percent reduction in fuel efficiency with RFG fuel means per capita demands in control areas may be larger than demands in non-control areas.

- Delivery of RFG to non-control areas (i.e., spillover).
- Reported delivery of RFG in one State (region) was actually sold in another State (region).

Oxygenate Demand

Oxygenates represent a key component of both Phase 1 and Phase 2 reformulated gasoline. The primary oxygenates include fuel ethanol, methyl tertiary butyl ether (MTBE), ethyl tertiary butyl ether (ETBE), and tertiary amyl methyl ether (TAME). Reformulated gasoline requires a minimum 2.1 percent oxygen by weight when averaging, which corresponds to approximately 6.0 volume percent ethanol, 11.5 volume percent MTBE, and 13.4 volume percent ETBE or TAME.

While EIA reports monthly data on production, imports, and stocks of individual oxygenates, there is no comparable data on the disposition of oxygenates. However, an oxygenate demand balance can be derived from EPA estimates of the oxygenate content in reformulated and oxygenated gasoline by control area. MTBE is the dominant blendstock in reformulated gasoline, and ethanol is generally the oxygenate of choice in oxygenated gasoline (Table 4). Almost all MTBE supply is used for reformulated and oxygenated gasoline blending, while only about one-half of the total ethanol supply is. Demand for ethanol in gasohol blending and MTBE as a motor gasoline octane blendstock make up the balance of the oxygenate demand.

[Estimated Oxygenate Demands by Control Area]

Table 4. Oxygenate Demand in Reformulated and Oxygenated Gasoline Control Areas, 1997
(thousands of barrels per calendar day)

Region	Estimated 1997 Gasoline Demand in Control Areas	Estimated Oxygenate Volume in Control Area Gasoline		
		MTBE	ETBE or TAME	Ethanol
Reformulated Gasoline				
PADD 1 - East Coast	1,052	110.8	8.7	0.7
PADD 2 - Midwest	282	4.2	0.0	22.4
PADD 3 - Gulf Coast	270	25.8	3.0	1.0
PADD 4 - Rocky Mountain	0	0.0	0.0	0.0
PADD 5 - West Coast	915	97.2	3.3	1.0
Subtotal U.S.	**2,522**	**238.1**	**15.0**	**24.2**
Oxygenated-Reformulated Gasoline				
PADD 1 - East Coast	138	17.8	0.0	1.6
PADD 5 - West Coast	13	0.1	0.0	1.2
Subtotal U.S.	**151**	**17.9**	**0.0**	**2.8**
Oxygenated Gasoline				
PADD 1 - East Coast	0	0.0	0.0	0.0
PADD 2 - Midwest	105	0.0	0.0	9.0
PADD 3 - Gulf Coast	19	0.0	0.0	1.7
PADD 4 - Rocky Mountain	36	0.3	1.1	2.5
PADD 5 - West Coast	73	0.5	0.0	5.1
Subtotal U.S.	**233**	**0.8**	**1.1**	**18.3**
Average 1997 Oxygenate Demand for RFG and Oxygenated Gasoline Blending		**257**	**16**	**45**
Imputed Oxygenate Demand for Conventional Gasoline (e.g., octane and gasohol)		**12**	**n.a.**	**37**
Total 1997 Oxygenate Supply		**269**	**n.a.**	**82**

n.a. - not available
Notes: Total oxygenate supply includes domestic production, net imports, and stock change. Imports of RFG

(161,000 barrels per day) assumed to contain 11.2 percent MTBE by volume.

Sources: Oxygenate content in RFG control area gasoline: Environmental Protection Agency, "1997 RFG Surveys Oxygenate Information" (http://www.epa.gov/orcdizux/consumer/fuels/mtbe/oxy-type.pdf). Oxygenate market shares in oxygenated gasoline control areas: Environmental Protection Agency, "State Winter Oxygenated Fuel Programs, February 1, 1999" (http://www.epa.gov/oms/regs/fuels/oxy-area.pdf). Control area gasoline demand calculated from control area population as share of State population and 1997 State gasoline demand from Federal Highway Administration, "Monthly Gasoline Reported by States," *Highway Statistics 1997*, FHWA-PL-98-020 (Washington, DC, Nov. 1, 998), Table MF-33GA. Oxygenate supply: Energy Information Administration, *Petroleum Supply Annual 1997*, *Volume 1*, DOE/EIA-0340(97)/1 (Washington, DC, June 1998), Tables 3, 20, 27, 30; and *Petroleum Supply Monthly*, DOE/EIA-0109 (Washington, DC, various issues), Tables D2, and D3.

Logistics

Reformulated gasoline is required in Dallas, Houston, and some of the urban areas in the Northeast and Midwest while a more stringent RFG is called for in California and Phoenix (Figure 1). Oxygenated gasoline is required in other parts of the Midwest and West, generally from mid-October through the end of February. New York City gets a hybrid oxygenated RFG during the winter. Adding another layer of complexity is a lower RVP gasoline that is delivered to more than 30 Air Quality Control Regions in the South from June 1 to September 15.

The proliferation of clean fuel requirements over the last decade has complicated petroleum logistics. Though the transition from Phase 1 to Phase 2 reformulated gasoline in early 2000 should not have a profound effect, additional clean fuels programs could make the system more vulnerable to local outages and price spikes.

Interstate Movements and Storage

Some parts of the country are more dependent than others on external gasoline supply sources.[8] Refineries on the East Coast, for example, provided only 29 percent of gasoline demanded in that region in 1997. Over 60 percent came from U.S. Gulf Coast refiners and the balance was imported. U.S. Gulf Coast supplies face constraints at pipeline breakout storage tanks and distribution terminals during the heating season. In the Midwest, 79 percent of the gasoline demanded was produced locally; 15 percent came from the U.S. Gulf Coast. Product pipelines going into the Midwest have little surplus capacity to handle extra batches of clean fuels. The pipeline companies blame the lack of expansion on poor return on investment as inflation-adjusted pipeline tariffs have declined over the last few years. U.S. Gulf Coast refiners also supplied 3 percent of West Coast demand. More U.S. Gulf Coast supply is expected in the West as the Navajo Pipeline is completed, allowing flows to southern Arizona. Imports accounted for under a percent of West Coast demand due, in part, to the stringent gasoline requirements in California.

An increasing number of gasolines and distillates of different quality grades, referred to as "product proliferation", leads to a loss in flexibility. Clean gasolines can become tainted and deemed off-spec if commingled with conventional gasoline. Therefore, pipelines must configure batches so that progressively lower grades of RFG, for example, are transported before progressively lower grades of conventional gasoline. Product interface requires downgrading gasoline from premium to regular gasoline and from RFG to conventional, and so forth. The downgrading of RFG to conventional gasoline, caused by product proliferation and the necessity of carrying multiple types of gasoline, reduces the amount of available RFG, thereby reducing the flexibility in supply.

Colonial Pipeline, operator of the U.S. Gulf Coast to New York trunk, has active product codes for 38 different grades of gasoline (including multiple vapor pressures for each grade), 7 grades of kerosene (including two for military), 16 grades of home heating oil and diesel fuel (including diesel fuel marine for the U.S. Navy and light cycle oil) and one grade of transmix (the gasoline/distillate interface that needs to be reprocessed). Of the 62 product codes, 29 are for fungible products and 33 are for products that must be shipped on a segregated basis.[9]

Furthermore, product proliferation has necessitated greater segregation at storage terminals, further complicating logistics. Terminaling facilities associated with pipelines are also faced with having to separate RFG, oxygenated, and conventional stocks at different grades and RVP levels. Storage terminals need to maintain RFG or other program gasoline supplies for a metropolitan area and conventional gasoline supplies for the surrounding area, sometimes in the same facility. In the past two winters, Colonial Pipeline Company limited nominations for shipments on its Houston-to-New York pipeline due to a problem of customers not clearing storage space for receipt of a new shipment. Handling errors were up during the same time period.[10]

Local Distribution

Based on evidence during the Phase 1 RFG program, industry faces more problems related to delivery rather than production. During Phase 1, the only situations where EPA considered suspension of RFG requirements were for distribution emergencies. EPA emergency provisions provide for a specification waiver until alternative RFG supplies can be obtained. A pipeline rupture on Colonial Pipeline's gasoline trunk just prior to the start of the RFG program caused officials to consider the delay of the start-up of the program. Barging supplies to another Colonial input point in Louisiana proved to be a viable alternative. A review of the waiver applications indicates that alternative supplies were ultimately available:

- In March 1997, flooding in the Ohio Valley prompted Ashland Oil to call EPA about the possibility of a waiver of regulations requiring reformulated gasoline in the Louisville and Covington areas of Kentucky. With help from the BP refinery in Toledo, Ohio, and the Marathon refinery in Robinson, Illinois, Ashland was able to forego a request for a waiver. Trucking proved to be a viable alternative to river supplies, though not completely free of flooding-related problems.
- In advance of losing an MTBE unit in Texas for a couple of weeks at the peak of the gasoline season in July 1997, Sun Oil called EPA about the possibility of a waiver of regulations requiring reformulated gasoline in the noncompliance areas in the Mid-Atlantic States. Sun was able to forego a formal request for a waiver after having found alternative supplies elsewhere in Texas that were barged to the Philadelphia facility.
- Facing the prospect of closing 11 gasoline stations in northern Kentucky in May 1998 due to a lack of reformulated gasoline (RFG) supplies, a jobber contacted EPA about the possibility of a waiver that would allow conventional gasoline to substitute for RFG.

> Ultimately, arrangements were made for the jobber to be resupplied out of a cargo received at a nearby terminal later in the day. The request for a waiver was withdrawn.

Price spikes were associated with each of these events and served as the basis for the first waiver application in March 1997. While the outage of the MTBE unit in Texas in July 1997 was resolved before local supplies and prices were impacted, the RFG cargo spot price in the New York Harbor went up, then receded by about a penny a gallon as suppliers reacted to the worsening of an already tight MTBE situation. An EIA survey picked up an 8-cent-per gallon week-to-week change in the average RFG retail price in Kentucky in connection with the May 1998 refinery problems.[(11)]

Phase 2 RFG Logistics

The conditions that existed for local distribution problems in Phase 1 will be carried forward into Phase 2. Other programs under consideration could effectively add more areas to the already hopscotched map of gasoline demand (Figure 1). Having to transport additional types of gasolines, interstate pipeline companies will be forced to generate more product codes and downgrade more gasoline tainted by contact with other gasoline types. Local distribution terminals may have to double the number of gasolines to segregate and, to accommodate this, will form more alliances with one type of gasoline stored at one facility and another type at a different facility. A summary of the future clean gasoline initiatives that could complicate the delivery of Phase 2 gasoline follows.

Possible Opt-Ins to the RFG Program

RFG is currently being suggested for four cities in addition to St. Louis, where RFG is set to start June 1, 1999. The combined demand for these four cities--Kansas City, New Orleans, Baton Rouge, and Lafayette--is about almost 200 thousand barrels per day (Table 5). While EPA has yet to approve these programs, offered as part of the Kansas and Louisiana State implementation plans (SIPs), early assessments show that the industry has the capability to produce, move, and distribute the proposed volumes.[(12)] RFG could come to these four cities as early as 2000.

Las Vegas is reviewing the possibility of using a special clean gasoline with specifications more in line with California's. The proposal also calls for an ethanol-only 3.5 weight percent oxygenate level that could arrive as early as November 1999, potentially adding another 57 thousand barrels per day to new RFG demand.

At the same time that some areas are opting into the RFG program, a controversy over MTBE is causing areas to consider opting out. MTBE, a suspected carcinogen, is appearing in ground water supplies. Maine opted out of the RFG program in March 1999. California is planning to phase out the use of MTBE by 2002.[(13)] A panel of experts has been established to advise EPA on how to address concerns about the use of MTBE and other oxygenates. The panel is scheduled to report to EPA its findings by summer 1999. The recommendations will address how to ensure public health protection for both air and water.

State Low Sulfur, Low RVP Gasoline Initiatives

Lowering RVP and sulfur circumvents the comparatively more expensive requirement for oxygenates in RFG while still reducing VOC emissions. Atlanta and Birmingham have plans for a low sulfur, low RVP gasoline. As with the RFG proposals, EPA has yet to approve 160 thousand barrels per day in total low sulfur, low RVP gasoline for these cities (Table 5). In addition, the regulations requiring RFG, complete with oxygenates, in ozone noncompliance areas may have to be repealed. The proposed gasoline has a summertime 7.0 psi RVP content and 150 ppm sulfur.

Some companies have offered to supply a low sulfur gasoline to service territories in the Eastern half of Texas while the State considers altering their SIP to require a low sulfur, low RVP fuel. Proximity to the Gulf Coast refining center and ample pipeline and storage capacity facilitates this discretionary, early move to a clean fuel. The demand for low sulfur, low RVP gasoline would start at almost 610 thousand barrels per day.

Table 5. Potential Total U.S. Requirement for Gasoline by Type
(thousands of barrels per day)

Program	1997	2000	2004	2010
Conventional	5,301	5,063	2,847	N/A
Oxygenated	233	271	297	330
Phase 1 RFG	2,674	N/A	N/A	N/A
Phase 2 RFG	N/A	2,857	3,056	3,313
Potential RFG Opt-In Areas (1)	N/A	257	258	259
Low Sulfur, Low RVP	N/A	160	770	771
Tier 2	N/A	N/A	1,997	4,368
1997 NAAQS (2)	N/A	N/A	N/A	975
Total Gasoline Consumption	**8,220**	**8,590**	**9,220**	**10,010**

Notes:
(1) As of March 31, 1999.
(2) Motor gasoline product quality requirements may not be substantially different from those of Phase 2 RFG.
N/A = not applicable.
Totals may not equal sum of components due to independent rounding.

Source: 1997 volumes from Energy Information Administration, *Petroleum Marketing Annual*, DOE/EIA-0487(98) (Washington, DC, June 1998), Table 50; U.S. Census Bureau. Forecast volumes from Energy Information Administration, *Annual Energy Outlook*, DOE/EIA-0383(99) (Washington, DC, December 1998), Table A11.

NAAQS

In July 1997, EPA finalized new attainment standards for ground-level ozone.[(14)] EPA is replacing the previous 1-hour ozone standard with a new 8-hour standard.[(15)] The new standards will have no immediate impact on energy markets; however, some impacts may be seen after 2004, when noncompliance areas are identified and control strategies are developed. Although SIPs will be unique to each State, all are likely to include strategies to reduce NOx and VOC emissions from such key sources as electric utilities, industries, and motor fuels consumption to address the tighter ozone standard.

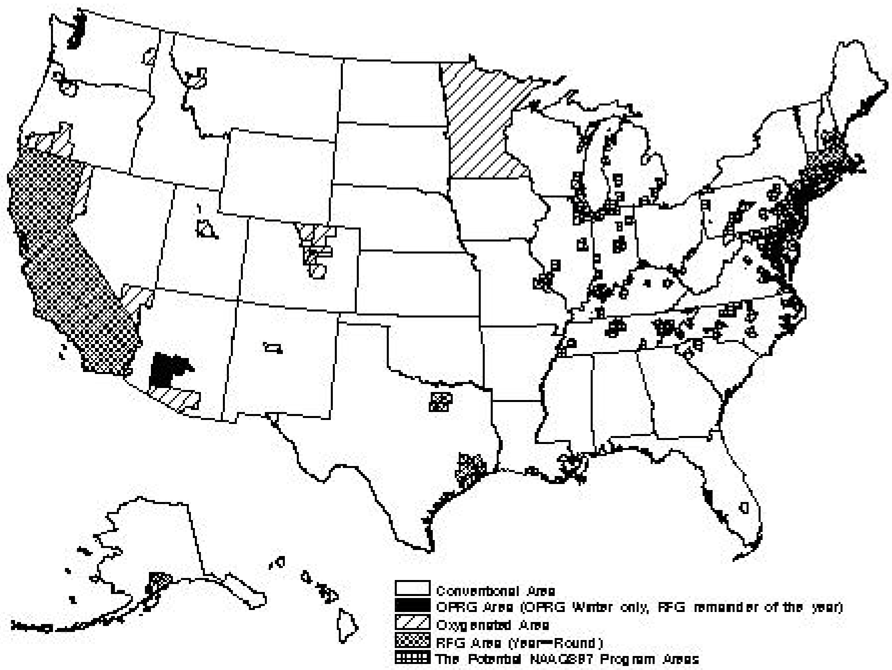
RFG use has led to a considerable reduction in VOC and NOx emissions, which are precursors to the formation of ozone. Therefore, RFG is likely to be included in SIPs. Examination on a county-by-county basis for large, noncomplying areas that have few other ozone-reducing alternatives results in a demand estimate for 2010 of almost a million barrels per day (Table 5) when fully implemented. This further complicates logistics by possibly adding counties in 10 States, mainly those in the Midwest and the South, to the RFG program (Figure 1).

Tier 2 Gasoline

EPA is considering a proposal to lower the sulfur content of gasoline from an average 340 ppm to as low as 30 ppm, approximating the California limit. The purpose of this move is to meet Tier 2 requirements to further reduce tailpipe emissions. Both the Tier 1 and 2 designations come from the 1990 Clean Air Act Amendments.[(16)] The low sulfur proposal would apply to all gasoline sold in the United States and, therefore, would be more a refining than a logistics issue. The industry is countering with proposals for a slower phase-in of the standard and more regionalization, a position that complicates delivery. If enacted in stages, terminals with service areas that straddle the Mississippi River could be looking at adding Tier 2 gasoline to their product slate and would need to segregate the various grades until the remaining States were phased in. EPA is currently developing a proposal for a trading program and a phase-in for small refiners, thereby requiring the segregation of Tier 2 gasoline through to any one of a number of destinations receiving conventional gasoline. While these proposals complicate logistics in many respects, Tier 2 could make the delivery of RFG in additional counties in 10 States, a possibility under the proposed NAAQS, unnecessary.

The demand for this gasoline effectively supplants conventional gasoline demand and carries with it the requirement for low summertime RVP in southern States. If enacted in stages, Tier 2 demand could start at 2.0 million barrels per day for 2004 (at a higher 150 ppm sulfur level) and be as much as 4.4 million barrels a day by 2010 (at the lower sulfur level, Table 5).

Figure. 1. Gasoline Formulations (Clean Air Act Amendments 1990 and National Ambient Air Quality Standards 1997)



Note: Does not include low RVP gasoline required in over 30 Air Quality Control Regions in OR, NV, UT, CO, KS, MO, TN, MD, and DE and States south.
Source: U.S. Environmental Protection Agency, State Environmental Offices, and Energy Information Administration estimates.

RFG Production Options

The application of the Phase 2 complex emissions model provides refiners some flexibility to meet the emissions reduction performance standards. The estimation of the Phase 2 RFG price premium depends on what fuel components will provide the most cost-effective means for reducing emissions.

Although the emissions reduction performance standards for Phase 2 RFG are based on comparison with emissions from the 1990 baseline gasoline fuel, the required emissions reductions and cost of Phase 2 RFG in this analysis are based on the emission reductions and costs incremental to those already realized in meeting the Phase 1 RFG standard. The minimum emission reduction requirements for Phase 1 RFG were established in the Introduction of this article (Table 1). MTBE is assumed to be the blended oxygenate because it is the most commonly used and most likely represents the oxygenate used at the margin. All emissions reduction performance standards are based on averaging, i.e., refiners will choose to achieve emissions reduction targets on average rather than on each gallon of gasoline produced.

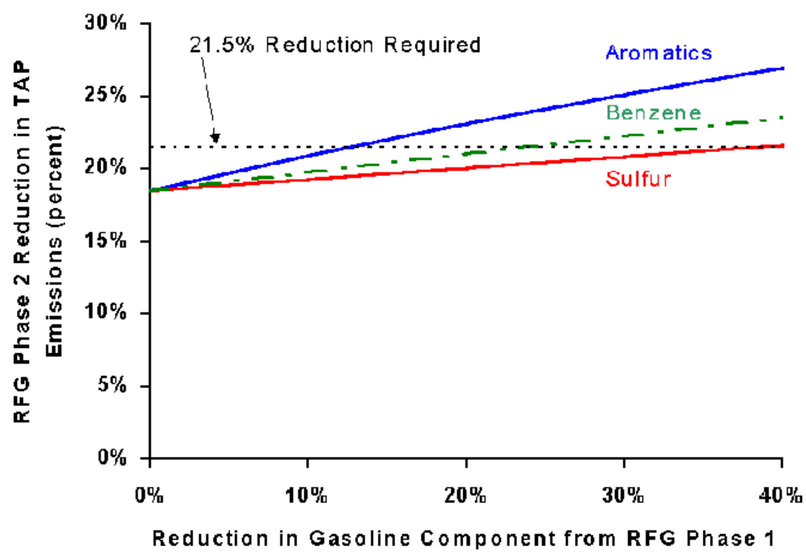
The impact of changes in the individual fuel components on TAP, NOx, and VOC emissions beyond the minimum requirements of Phase 1 are presented in graphs. This analysis indicates that RVP, sulfur, and aromatics are the fuel components that have the greatest impact on TAP, NOx, and VOC emissions and should be the primary targets of refiner Phase 2 RFG quality control.

Toxic Air Pollutants (TAP) Reduction

Phase 2 RFG requires a year-round 21.5 percent reduction in TAP emissions from the 1990 baseline gasoline. Phase 1 RFG already produces an average 18 percent reduction and only a small improvement is required to achieve the Phase 2 target (Table 1).

The three dominant variables in TAP emissions reduction are aromatics, benzene, and sulfur (Figure 2). Changes in RVP, olefins, E200 and E300 (not shown in graph) have only small effects on TAP. Replacing MTBE with ethanol increases TAP emissions because of the higher production of formaldehyde and acetaldehyde. The additional 3.5 percent reduction in TAP emissions (over current Phase 1 requirements) can be accomplished either by a 13 percent reduction in aromatics (from 32 to 28 volume percent), by a 24 percent reduction in benzene (from 0.95 to 0.72 volume percent), or by a 39 percent reduction in sulfur (from 312 to 190 ppm).

Figure 2. RFG Phase 2 TAP Reduction by Gasoline Component

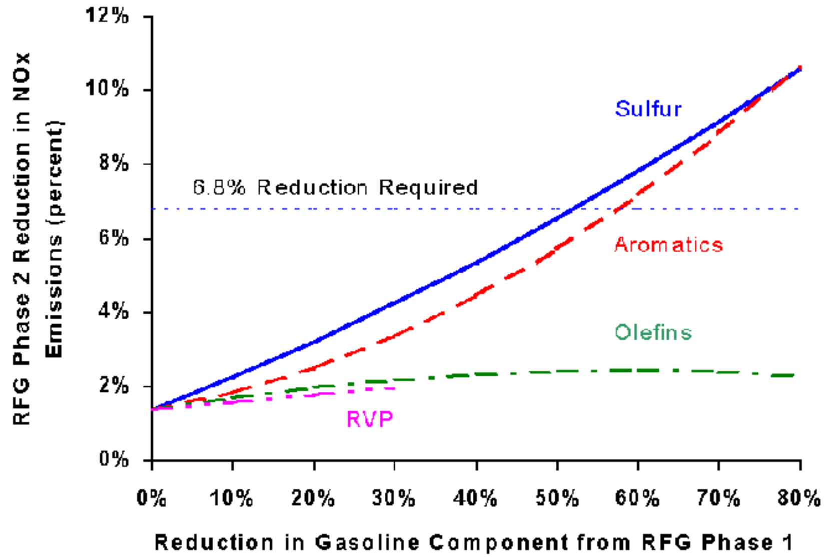


Nitrogen Oxides (NOx) Reduction

Phase 2 RFG requires a 6.8 percent reduction in NOx during the summer months and a winter reduction of 1.5 percent. Phase 1 RFG already produces an average 1.5 percent reduction in NOx year-round. Thus, the required summer NOx emission reduction is the performance standard of interest.

Sulfur and aromatics dominate the NOx emissions equation (Figure 3). Olefins, RVP, E200, and E300 have only small effects, and benzene has no effect on NOx emissions. The additional 5.3 percent reduction in NOx emissions (over current Phase 1 requirements) during the summer months can be accomplished either by a 52 percent reduction in sulfur (from 312 to 150 ppm) or by a 58 percent reduction in aromatics (from 32 to 13.6 volume percent).[(17)]

Figure 3. RFG Phase 2 NOx Reduction by Gasoline Component

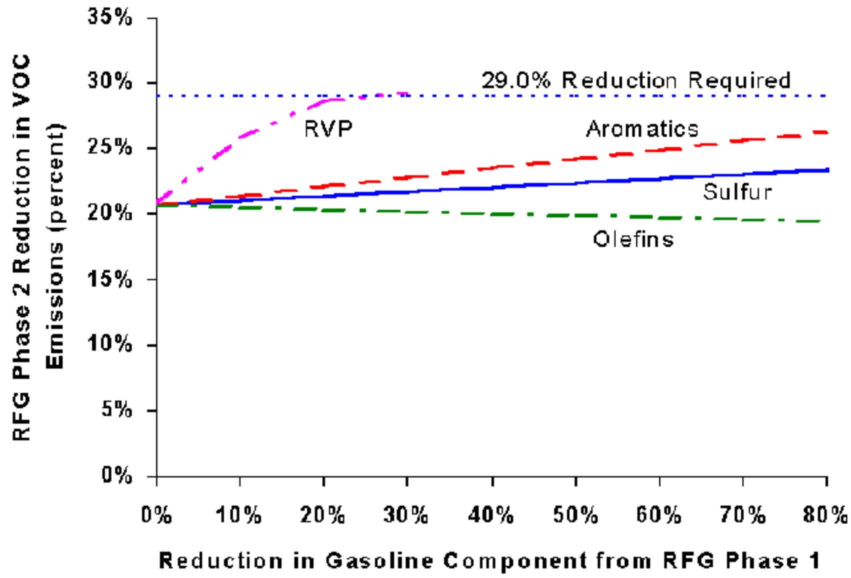


Volatile Organic Compounds (VOC) Reduction

The Phase 2 VOC emissions reduction performance standards for southern States (region 1) and northern States (region 2) are almost identical. However, the required incremental VOC emissions reduction beyond Phase 1 RFG is much greater in region 2 because Phase 1 RFG requires a much smaller reduction in VOC emissions in region 2 (Table 1).

RVP dominates the VOC emissions calculation (Figure 4). Reductions in aromatics and sulfur make small contributions to lower VOC emissions. However, reductions in RVP alone will not be enough to achieve the required Phase 2 VOC reduction.[(18)] A reduction in RVP to 6.7 psi will reduce VOC emissions by about 24 percent in region 1, and 22 percent in region 2, well below the 29 percent and 27.4 percent required in regions 1 and 2, respectively. Reducing sulfur from 300 to 140 ppm will yield an additional reduction of 1.9 percent. Lowering aromatics from 32 to 26 volume percent adds another 1.5 percent VOC reduction. Still, this is not enough. The final necessary emissions reductions must come from increasing E200, E300, and olefins, without violating the NOx emissions reduction requirement (the TAP emissions requirement is not binding).

Figure 4. RFG Phase 2 VOC Reduction by Gasoline Component



Summary of RFG Production Options

Sulfur, RVP, and total aromatics are the fuel components that have the greatest impact on TAP, NOx, and VOC emissions, and should be the primary targets of refiner Phase 2 RFG quality control.

Because of the required addition of oxygenates, the level of aromatics has already been reduced significantly below the 1990 baseline gasoline composition. In fact, Phase 1 RFG that is currently being produced should already meet the Phase 2 TAP emissions reduction performance standard. The addition of 11 volume percent MTBE (or 6 volume percent fuel ethanol) contributes to a reduction in aromatics in two ways. First, there is a simple dilution effect. For example, adding 11 gallons of MTBE to 89 gallons of conventional gasoline with 32 volume percent aromatics will result in a blend with 28.5 volume percent aromatics (or 30 volume percent aromatics when diluted with 6 volume percent fuel ethanol). Second, the addition of oxygenates, which are high in octane, allows refiners to reduce the conversion of low octane gasoline components to high octane aromatics in Reformers.[(19)] This oxygenate blending effect can be seen in Phase 1 RFG that was produced during the winter 1997-1998 (Table 6). The addition of oxygenates also increases the percentage of gasoline that boils off at temperatures below 200 and 300 degrees Fahrenheit (i.e., E200 and E300).

Table 6. Reformulated Gasoline Quality Survey Results, Winter 1997-1998				
	1990 Winter Baseline	**Reformulated Gasoline, Winter 1997 - 1998**		**Phase 2 RFG Winter Requirements**
		With Ethers	**With Ethanol**	
Product Quality:				
Oxygenate (weight %)				2.1 % min
MTBE	0	1.98	0.05	
TAME	0	0.09	0.00	
Ethanol	0	0.00	3.52	
Sulfur (ppm by weight)	338	144	193	
Aromatics (volume %)	26.4	20.1	22.4	
Benzene (volume %)	1.64	0.68	0.76	0.95 % max
Olefins (volume %)	11.9	6.6	10.2	
E200 (volume %)	50	56	n.a.	
E300 (volume %)	83	86	n.a.	
Emissions Reduction from Baseline (percent):				
TAP	0	27.7 %		21.5 % min
NOx	0	9.9 %		1.5 % min

n.a. - not available
Notes: Winter 1997 - 1998 corresponds to December 1997 through February 1998. Emissions reduction from baseline is calculated by using RFG Phase 2 complex emissions model.

Sources: 1990 Winter Baseline and RFG Phase 2 Winter Requirements: Code of Federal Regulations, Title 40, Part 80, "Regulation of Fuels and Fuel Additives." Reformulated Gasoline, Winter 1997 - 1998: National Institute for Petroleum and Energy Research, *Motor Gasolines, Winter 1997-98* (Bartlesville, OK, August 1998), Table 5.

Costs of Reformulated Gasoline

The clean air benefits of reformulated gasoline do not come freely. Consumers are faced with two costs of reformulated gasoline. First, the price of Phase 2 reformulated gasoline at the pump is expected to be 2.5 to 4.0 cents per gallon higher than conventional (non-reformulated) gasoline, depending on the region on the country and the time of year. Compared with the cost of Phase 1 RFG, no increase is expected during the winter months and a 1.0 to 1.5 cent per gallon increase is expected during the summer months in southern and northern States, respectively.

Second, the fuel economy (miles per gallon) of Phase 2 RFG is about 1.5 to 2 percent lower than conventional gasoline because the energy (Btu) content of RFG is lower than that of conventional gasoline. This fuel economy penalty is unchanged from the fuel economy penalty realized with the use of Phase 1 RFG.

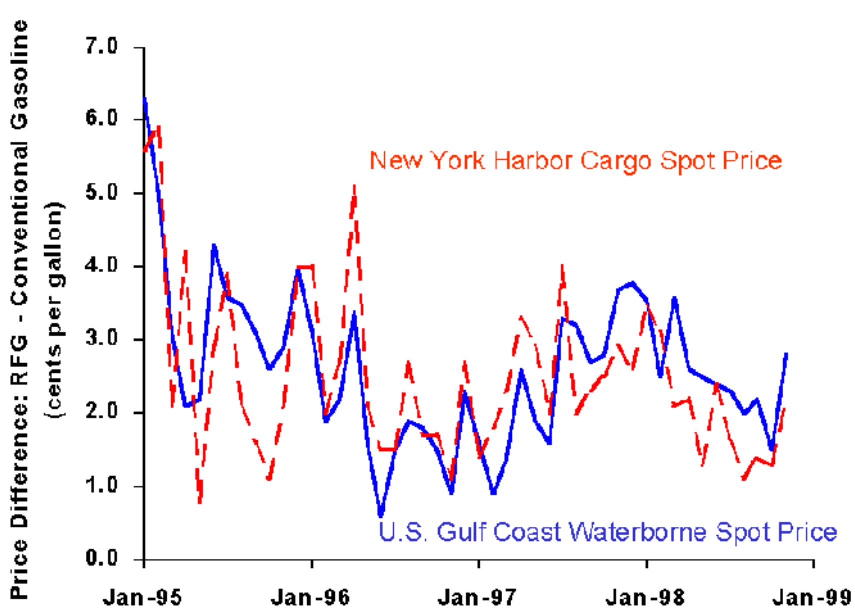
Two sources of data are available to bracket the expected wholesale market price premium for Phase 2 reformulated gasoline over conventional gasoline. First, the historical price premium for Phase 1 RFG provides a lower bound for the estimate (2.3 cents per gallon). Second, the historical price premium for California clean gasoline, which has stricter requirements for emissions reductions, should provide an upper bound for the expected price premium (4.3 cents per gallon).

Phase 1 RFG Price Premium

Before the start of the reformulated gasoline program in 1995, EIA originally projected a Phase 1 RFG price premium of 3.5 to 4 cents per gallon over conventional gasoline.[(20)] The price premium is due primarily to the required 2.1 percent by weight of oxygenates (equivalent to about 11.5 percent MTBE, or 6.0 percent fuel ethanol by volume), which made up 3.0 cents of the projected Phase 1 RFG price premium. The additional requirements for RVP reduction in the summer and reducing the levels of benzene and other aromatics were projected to add 0.4 cents per gallon and 0.5 cents per gallon, respectively, to the cost of reformulated gasoline.

The actual wholesale price premium for Phase 1 RFG has generally fallen in the range of 2 to 4 cents per gallon (Figure 5). The variability in the Phase 1 RFG price premium has been due to changes in the cost of oxygenates, particularly MTBE, relative to the cost of gasoline.[(21)] The wholesale price difference between Phase 1 RFG and conventional gasoline has averaged 2.3 cents per gallon for both U.S. Gulf Coast and New York Harbor waterborne cargoes (from January 1996 to December 1998).

Figure 5. Price Difference: Reformulated - Conventional Regular Gasoline (cents per gallon)



Source: DRI/McGraw-Hill, *Platt's Oilgram Price Report, Price Average Supplement* (New York, NY), various issues 1995 - 1998.

California Clean Gasoline Price Premium

California began its own clean gasoline program in early 1996. The California clean gasoline (referred to as "CARB" gasoline because the program is administered by the California Air Resources Board) has stricter gasoline quality and emissions reduction performance standards than EPA Phase 2 RFG (Table 7).

The wholesale (pipeline) price difference between CARB clean gasoline and conventional gasoline has averaged 4.2 cents per gallon in Los Angeles and 4.3 cents per gallon in San Francisco (from January 1997 to December 1998) (Figure 6).

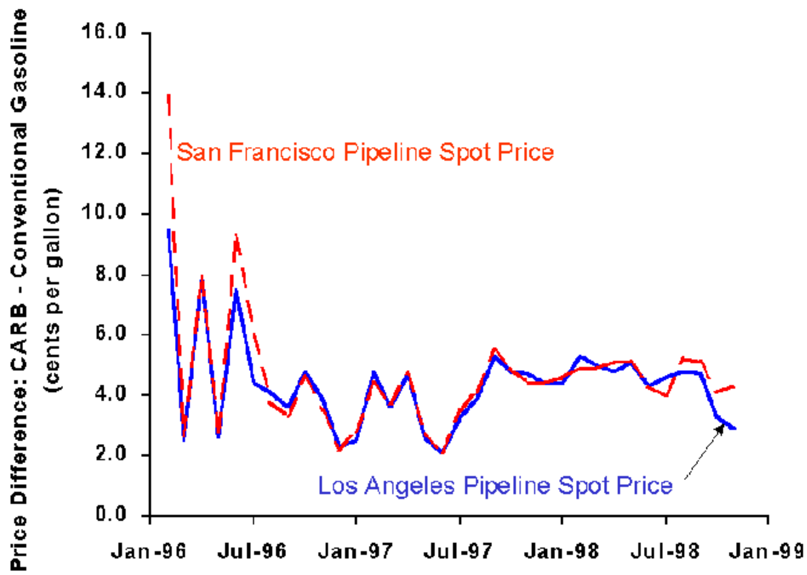
Table 7. Reformulated Gasoline Averaging Standards

		Phase 2 RFG, January 2000		
	CARB Gasoline	Summer Region 1	Summer Region 2	Winter
Product Quality Standards:				
RVP, psi max	7.0			
Oxygen, wt % min	2.0	2.1	2.1	2.1
Benzene, vol % max	0.8	0.95	0.95	0.95
Aromatics, vol % max	22.0			
Olefins, vol % max	4.0			
Sulfur, ppm	30.0			
Distillation temperatures:				
50% Distilled, degrees F max	200			
90% Distilled, degrees F max	290			
Performance Standards, percent reduction required:				
Toxic Air Pollutants	34.4 %	21.5 %	21.5 %	21.5 %
Volatile Organic Compounds	27.9 %	29.0 %	27.4 %	n.a.
Nitrogen Oxides	14.6 %	6.8 %	6.8 %	1.5 %

Notes: Performance standards for CARB gasoline are calculated by using EPA Phase 2 complex emissions model.

Sources: RFG specifications: Environmental Protection Agency, "Regulation of Fuel and Fuel Additives," Code of Federal Regulations, Title 40, Part 80. California specifications: California Air Resources Board, "The California Reformulated Gasoline Regulations," Title 13, California Code of Regulations, Sections 2250-2272 (as last amended July 2, 1996).

Figure 6. Price Difference: California (CARB) Clean Gasoline - Conventional Regular Gasoline (cents per gallon)



Source: DRI/McGraw-Hill, *Platt's Oilgram Price Report*, *Price Average Supplement* (New York, NY), various issues 1996 - 1998.

Phase 2 RFG Price Premium

Phase 1 RFG should already meet the year-round TAP and winter NOx emissions reduction performance standards. Thus, there should be no additional price premium for Phase 2 RFG over Phase 1 RFG during the winter months. The summer VOC and NOx emissions reduction performance standards will require reductions in total aromatics, RVP, and sulfur.

Aromatics Reduction. Although reducing the level of aromatics in motor gasoline significantly reduces NOx emissions, this is generally not considered a cost-effective method of control (beyond the level already achieved with the addition of oxygenates).

RVP Reduction. Lowering RVP increases the refiner's cost of producing gasoline because low-cost normal butane (C4s) must be removed from the gasoline pool. Since the start of the RFG program in 1995, the price of normal butane (at Mont Belvieu, Texas) has averaged 17 cents per gallon below the price of conventional regular gasoline (U.S. Gulf Coast waterborne cargoes) during the summer months (May through August).[(22)] A 1 psi reduction in RVP requires about a 2 volume percent reduction in the concentration of normal butane in gasoline.[(23)] Based on a simple linear blend calculation, the removal of 2 volume percent normal butane from gasoline would increase the price of gasoline by about 0.34 cents per gallon. There is an additional cost of about 0.1 cents per gallon per psi reduction for the loss of octane that butane provides the gasoline pool.[(24)] Thus, the cost of removing butane on the basis of a simple blending economics is about 0.44 cents per gallon per psi reduction.

A comparable estimate of the cost of RVP reduction can be obtained from the market price differential between 7.8 and 9.0 RVP gasoline. The wholesale market price premium for 7.8 RVP gasoline relative to 9.0 RVP gasoline on the U.S. Gulf Coast during the summers of 1993 through 1998 (May through August) averaged 0.52 cents per gallon, which is equivalent to a price premium of about 0.43 cents per gallon per 1 psi reduction. EPA estimated RVP reduction costs to average 0.42 cents per gallon per 1 psi.

Phase 2 RFG will require approximately a 1.3 psi reduction in RVP (from 8.0 to 6.7 psi) in northern control areas (region 2) and a 0.4 psi reduction (from 7.1 to 6.7 psi) in southern areas (region 1) from current Phase 1 RFG levels during the summer months. EIA estimates the average cost for reducing RVP from Phase 1 to Phase 2 RFG levels during the summer months to be about 0.6 cent per gallon (1.3 psi multiplied by 0.45 cent/gallon/psi reduction) in northern control areas and 0.2 cent per gallon in the southern control areas.

Sulfur Reduction. Sulfur occurs naturally in crude oil. As crude oil is refined, some of the sulfur ends up in motor gasoline. The sulfur in crude oil is generally concentrated in the heavier components such as distillate and residual fuel oils. Most sulfur in motor gasoline (80 to 90 percent) comes from the conversion of the heavier components to gasoline in fluid catalytic cracking (FCC) units, which produce about one-third of the U.S. motor gasoline pool.[(25)] The sulfur in untreated FCC gasoline product ranges as high as 1,000 to 2,000 ppm. There are two general process options for reducing sulfur. The first option involves diversion of the heavy FCC product that is highest in sulfur to the distillate fuel oil pool. This is the lowest capital and operating cost option, but results in the downgrade of gasoline product to lower-valued fuel oil and reduces the volume of motor gasoline produced. The second option involves hydrotreating either the feed to or the product from the FCC unit. Hydrotreating to remove sulfur may have high capital and operating costs but maintains the volume of the gasoline pool.

The expected cost for removing sulfur is highly dependent on a refiner's available hydrotreating capacity and the share of total gasoline production that must be reformulated. EPA originally estimated the cost of reducing sulfur from 340 ppm down to 250 ppm to be 0.18 cent per gallon and the cost of going from 250 ppm down to 160 ppm to be 0.56 cent per gallon.[(26)] More recently, EPA estimated the cost for all PADD 1 and 3 refiners to reduce sulfur from 340 ppm down to 150 ppm to range from 1.1 to 1.8 cent per gallon.[(27)] We expect that sulfur reduction for Phase 2 RFG will cost on average 0.8 cent per gallon.

Total Incremental Phase 2 Summer RFG Production Cost. Refiners will take different paths to produce Phase 2 RFG. On average, we expect Phase 2 RFG during the summer months to be low in RVP (6.7 psi) and low in sulfur (140 ppm). In addition, the blending of oxygenates will contribute to lower aromatics (26 volume percent or less) and raise E200 (to 50 volume percent). The costs of reducing RVP and sulfur during the summer months are expected to add about 1.5 and 1.0 cents per gallon to the cost of supplying Phase 1 RFG to the northern (region 2) and southern (region 1) States, respectively. The cost to produce Phase 2 RFG during the winter months should be no greater than the current cost to produce Phase 1 RFG.

Since the wholesale price difference between Phase 1 RFG and conventional gasoline has averaged close to 2.5 cents per gallon throughout the year, we expect the wholesale price of

Phase 2 RFG to average about 2.5 cents per gallon above the price of conventional gasoline during the winter. During the summer months, Phase 2 RFG is expected to average 4.0 cents per gallon above the price of conventional gasoline in northern States, and 3.5 cents per gallon above the price of conventional gasoline in southern States. This expected price premium is lower than the wholesale price difference between CARB clean gasoline and conventional gasoline in California.

Reduced Fuel Economy

The fuel economy (miles per gallon) of Phase 1 and Phase 2 RFG is about 1.5 per cent lower during the summer and 2 percent lower during the winter because the energy (Btu) content of RFG is lower than that of conventional gasoline. This corresponds to about 0.4 to 0.6 miles per gallon for a car that averages 27 miles per gallon. The decline in fuel economy is due primarily to the required use of oxygenates, which have a lower energy content than that of the conventional motor gasoline or octane blendstocks (e.g., aromatics) that the oxygenates displace. This loss is offset partially by the lower summer RVP requirement, which will reduce both evaporative emissions and the volume of butane, which is low in energy content, in motor gasoline.

Reformulated gasoline with 11.5 volume percent MTBE has a Btu value that is about 2.1 percent lower than that of conventional motor gasoline, while motor gasoline reformulated with 6 volume percent ethanol has a Btu content that is about 2.0 percent lower than that of conventional gasoline (Table 8).

Table 8. Fuel Economy Loss With Oxygenate Blending

Oxygenate	Energy Content of Oxygenate (Btu/gallon)	Volume Percent Oxygenate	Volume Percent Gasoline	Energy Content of 1 Gallon of Blend (Btu/gallon)	Percent Energy Reduction Compared with Gasoline
MTBE	93,500	11.5	88.5	111,642	2.1
Ethanol at 6 vol. %	76,000	6.0	94.0	111,720	2.0
Ethanol at 10 vol. %	76,000	10.0	90.0	110,200	3.3
TAME	100,600	13.4	86.6	112,204	1.6
ETBE	97,700	13.4	86.6	111,816	1.9

Notes: Energy content of gasoline is 114,000 Btu/gallon.

Source: Energy contents of oxygenates and gasoline are from American Petroleum Institute, *Alcohols and Ethers: A Technical Assessment of Their Applications as Fuel and Fuel Components*, Publication 4261, Second Edition (Washington, DC, December 13, 1993), p. 334.

The required reduction of RVP during the summer months partially offsets the decline in fuel economy due to the addition of oxygenates. Refiners reduce RVP by removing light hydrocarbons like normal butane. A 2 volume percent reduction in normal butane results in an approximately 1 psi reduction in RVP, and a 0.3 percent increase in energy content and fuel economy.[(28)] Some additional (unestimated) benefit is realized due to reduced fuel losses through evaporation from the gas tank and while fueling a car.

A number of on-road studies of the fuel economy effects of reformulated gasoline have been conducted that confirm the theoretical estimates of fuel economy loss based on energy content: fuel economy is reduced by 2 to 3 percent during the winter season and 1 to 2 percent during the summer season.[(29)]

Conclusion

As the Phase 2 RFG program goes into effect, the estimated market share for RFG should continue to represent about one-third of total U.S. gasoline demand. Refiners are expected to lower the RVP, sulfur, and aromatics content of RFG in order to meet the summer VOC and NOx reductions required under the Phase 2 RFG program. The cost of producing Phase 2 RFG is expected to represent a price premium of 2.5 to 4.0 cents per gallon over the cost of producing conventional motor gasoline, depending on the region on the country and the time of year. The price of MTBE, ethanol, and other oxygenates could change the cost estimate by a penny either direction.

No changes are required to transport and distribute Phase 2 RFG, compared with Phase 1 RFG. However, the delivery of a number of different grades of gasoline to specific areas at certain times of the year has led to local supply problems and limited price spikes. Future regulations requiring the phase-in of additional localized clean fuel requirements are expected to add to the potential for localized supply disruptions.

Guide to Abbreviations and Acronyms

Btu - British thermal unit
CAA90 - Clean Air Act Amendments of 1990 (Public Law 101-549)
CARB - California Air Resources Board
E200 - Percent of fuel evaporated at 200 degrees Fahrenheit
E300 - Percent of fuel evaporated at 300 degrees Fahrenheit
EIA - Energy Information Administration, U.S. Department of Energy
EPA - U.S. Environmental Protection Agency
ETBE - Ethyl tertiary butyl ether
FCC - Fluid catalytic cracking unit
FHWA - Federal Highway Administration
MTBE - Methyl tertiary butyl ether
NAAQS - National ambient air quality standard

NOx - Nitrogen oxide
PADD - Petroleum Administration for Defense District
ppm - Parts per million
psi - Pounds per square inch
RFG - Reformulated gasoline
RVP - Reid vapor pressure
SIP - State implementation plan
TAME - Tertiary amyl methyl ether
TAP - Toxic air pollutants
VOC - Volatile organic compound

Endnotes

(1) Tancred Lidderdale (202-586-7321; Tancred.Lidderdale@eia.gov) is a refining industry analyst in the Energy Information Administration's Office of Energy Markets and End Use. Aileen Bohn (202-586-4255; abohn@eia.doe.gov) is an industry economist in the Energy Information Administration's Office of Oil and Gas.

(2) Environmental Protection Agency, *National Air Quality and Emissions Trends Report 1997*, 454/R-98-016 (Washington, DC, December 10, 1998).

(3) Ground-level ozone is the primary ingredient of smog and should not be confused with stratospheric ozone that is a natural layer some 6 to 20 miles above the earth and provides protection from harmful radiation.

(4) The St. Louis program will begin on May 1, 1999, for all persons other than retailers and wholesale purchaser-consumers (i.e., refiners, importers, and distributors). Environmental Protection Agency, *Federal Register*, Vol. 64 No. 41 (Washington, DC, March 3, 1999), pp. 10365-10371.

(5) A simple ordinary least squares regression analysis of State per capita motor gasoline demand (gallons per person per year) against the percentage of the State's population living in nonmetropolitan areas results in the following equation (t-statistics in parentheses):

State per capita demand (1997) =	428.8 + 2.22 * State nonmetropolitan population share (July 1, 1996) (7.57) (6.04)

(6) State demands from Federal Highway Administration, "Motor Gasoline Reported by States" *Highway Statistics 1997*, FHWA-PL-98-020 (Washington, DC, Nov. 1, 1998), Table MF-33GA. Estimated State population on July 1, 1996, from U.S. Census Bureau.

(7) EIA gasoline sales data are collected from a survey of about 200 "prime suppliers" -- firms that produce, import, or transport petroleum products across State boundaries and local marketing areas and sell the products to local distributors, local retailers, or end users. The

Federal Highway Administration collects total gasoline sales data from State fuel taxation reports, which generally represent gasoline sales at the terminal or wholesale level.

(8) Energy Information Administration, *Petroleum Supply Annual 1997*, Volume 1, DOE/EIA-0340(97/1) (Washington, DC, June 1998), Tables 4, 6, 8, 10, 12, and 32.

(9) Colonial Pipeline Company (http://www.colpipe.com/ab_faq.asp), February 18, 1999.

(10) Discussion with Noel Giese, Colonial Pipeline Company, January 5, 1999.

(11) Energy Information Administration, Form EIA-878, "Motor Gasoline Price Survey." May 4 and May 11, 1998.

(12) Energy Information Administration, "Availability of RFG Supplies," unpublished paper provided to the U.S. Environmental Protection Agency, April 10, 1998.

(13) For further information, see California Energy Commission, *Supply and Cost of Alternatives to MTBE in Gasoline*, P300-98-013 (Sacramento, CA, October 1998).

(14) Much of the following discussion is taken from Energy Information Administration, *Annual Energy Outlook 1998*, DOE/EIA-0383(98) (Washington DC, December 1997), pp. 12-15.

(15) A National Ambient Air Quality Standard (NAAQS) for ground-level ozone has three parts: the concentration or level, the measurement period, and the "form" of the standard. The new ozone standard is set at a concentration of 0.08 ppm and the measurement period is 8 hours. Under the form adopted by EPA, areas are allowed to disregard their three worst measurements every year and average performance over three years to determine if they meet the standard.

(16) An analysis of Tier 2 supply and costs is contained in: Energy Information Administration, *Annual Energy Outlook 1999*, DOE/EIA-0383(99) (Washington DC, December 1998), pp. 29-30.

(17) The EPA originally established the NOx standard on the basis of the level of NOx control that can be cost-effectively achieved through sulfur reduction down to 138 ppm: Environmental Protection Agency, *Final Regulatory Impact Analysis for Reformulated Gasoline* (Washington, DC, December 13, 1993), p. 396.

(18) The EPA established the VOC standard based on the level of VOC control that can be cost-effectively achieved through RVP reduction down to 6.7 psi, in addition to VOC reduction achieved by reducing sulfur to meet the NOx standard: Environmental Protection Agency, *Final Regulatory Impact Analysis for Reformulated Gasoline* (Washington, DC, December 13, 1993), p. 396.

(19) Reformer product (reformate) contains about 66 percent aromatics and makes up about 27 percent of the total motor gasoline pool: National Petroleum Council, *U.S. Petroleum Refining*, Volume VI (Washington, DC, August 1993), pp. N242-N244. The road octane (R+M/2) of

MTBE is 109, compared with an average 104.1 road octane for aromatics: Robert E. Maples, *Petroleum Refinery Process Economics* (PennWell Books: Tulsa, OK, 1993), Table 5-1.

(20) Tancred Lidderdale, "Demand, Supply, and Price Outlook for Reformulated Motor Gasoline, 1995," *Monthly Energy Review*, DOE/EIA-0035 (94/07) (Washington, DC, July 1994), pp.1-10. Using a more rigorous refinery model, EPA estimated the national average Phase 1 RFG cost would range from 1.6 to 3.5 cents per gallon (excluding the cost of oxygenates already required in oxygenated gasoline control areas during the winter), depending on the price of oxygenates: Environmental Protection Agency, *Final Regulatory Impact Analysis for Reformulated Gasoline* (Washington, DC, December 13, 1993), p. 303.

(21) The strong relationship between the cost of MTBE and the price premium for Phase 1 RFG is evident from the comparison of the price difference between MTBE and conventional gasoline with the price difference between RFG and conventional gasoline. This was illustrated in an earlier EIA analysis article:"Environmental Regulations and Changes in Petroleum Refining Operations" (June 1998) http://www.eia.gov/emeu/steo/pub/special/enviro.html.

(22) McGraw-Hill, Inc., *Platt's Oilgram Price Report*, *Price Average Supplement* (New York, NY), various issues 1995 - 1998.

(23) Based on a normal butane blending RVP of 60 psi.

(24) Based on the octane contribution to regular gasoline from normal butane with a road octane (R+M/2) of 92.1, being replaced with MTBE and a road octane of 110. Octanes from Robert E. Maples, *Petroleum Refinery Process Economics* (PennWell Books: Tulsa, OK, 1993), Table 5-1.

(25) "Pipeline Hydrogen Supply Provides Flexibility and Alternative Solutions to Improve Returns on Refinery Assets," *Hart's Fuel Technology and Management's Sulfur 2000* (Summer 1998), pp. 26-28; and "Low-Sulfur Specifications Cause Refiners to Look at Hydrotreating Options," *Oil & Gas Journal* (December 8, 1997), pp. 47-51.

(26) Environmental Protection Agency, *Final Regulatory Impact Analysis* (Washington, DC, December 13, 1993), Table VI-6.

(27) Environmental Protection Agency, *EPA Staff Paper on Gasoline Sulfur Issues* (Washington, DC, May 1, 1998), p. 32.

(28) Based on a normal butane blending RVP of 60 psi and a heat content of 95,040 Btu per gallon.

(29) White House Office of Science and Technology Policy, "Fuel Economy and Engine Performance Issues," *Interagency Assessment of Oxygenated Fuels* (Washington, DC, June 1997), Chapter 3; Lawrence Livermore National Laboratory, *Assessment of California Reformulated Gasoline Impact on Vehicle Fuel Economy*, UCRL-ID-126551 (Livermore, CA, January 1997).

Summary of Revisions to Article

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Revisions August 6, 1999:

- Corrected startup date of the Phase 2 RFG program to January 1, 2000 for refineries and all points in the distribution system.
- Revised Table 4 oxygenate demands and added URL address of MS Excel spreadsheet with details of calculations at the control-area level.

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