Environmental Regulations and Changes in Petroleum Refining Operations

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Spreadsheets Referenced in this Article

- Supporting Data for this Analysis Report

Related EIA Analysis Products

- Demand and Price Outlook for Phase 2 Reformulated Gasoline, 2000
- Demand, Supply, and Price Outlook for Reformulated Motor Gasoline, 1995
- Areas Participating in the Reformulated Gasoline Program
- Areas Participating in Oxygenated Gasoline Program
- Oxygenate Supply/Demand Balances in the Short-Term Integrated Forecasting Model
- Impact of Environmental Compliance Costs on U.S. Refining Profitability
- 1995 Reformulated Gasoline Market Affected Refiners Differently
- Refiners Switch to RFG Complex Model

Introduction

The U.S. petroleum industry has responded to 4 major new federal rules on motor gasoline product quality in the last 10 years:

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

These regulations have generated significant changes in domestic refinery operations, affecting production, marginal production costs, and market prices. Some changes have been dramatic. The price of motor gasoline has increased by as much as 7 cents per gallon because of the regulations.

These changes in domestic refining operations are identified and related to the summer Reid vapor pressure (RVP) restrictions and oxygenate blending requirements. This analysis uses published EIA survey data and linear regression equations from the *Short-Term Integrated Forecasting System (STIFS)*. The *STIFS* model is used for producing forecasts appearing in the *Short-Term Energy Outlook*.

Motor Gasoline Summer Volatility (RVP) Regulations

The Environmental Protection Agency (EPA) implemented a two-phase program to reduce summertime gasoline volatility measured as Reid vapor pressure (RVP). Phase I of the RVP regulations went into effect on June 1, 1989, and Phase II became effective on May 1, 1992 (Table 1). The new RVP standards were established for each of the 48 contiguous States during the summer months of May 1 through September 15.

The reformulated gasoline (RFG) program, which began on January 1, 1995, required additional reductions in RVP during the summer months in ozone nonattainment areas that are required to participate or opt into the program. The RFG program covers about 1/3 of the total U.S. motor gasoline market (for a list of RFG program areas, refer to "Areas Participating in the Reformulated Gasoline Program".)

Table 1. Summer Volatility Regulations for Motor Gasoline (Pounds per Square Inch Reid Vapor Pressure)					
Region	**ASTM Class**	**Before Jun. 1, 1989**	**RVP Phase I Jun. 1, 1989 to Apr. 30, 1992**	**RVP Phase II After May 1, 1992**	**Conventional / Reformulated Gasoline After Jan. 1, 1995**
Ozone Attainment Areas					
Northern U.S.	C	11.5	10.5 *	9.0	9.0 / n.a.
Southern U.S.	B	10.5	9.5	9.0	9.0 / n.a.
Southern U.S.	A	9.0	9.0	9.0	9.0 / n.a.
Ozone Nonattainment Areas					
Northern U.S.	C	11.5	10.5 *	9.0	9.0 / 8.1**
Southern U.S.	B	10.5	9.5	7.8	7.8 / 7.2**
Southern U.S.	A	9.0	9.0	7.8	7.8 / 7.2**
Notes:	n.a. = not applicable Enforcement begins on June 1 for retail stations. Enforcement begins May 1 for all other points in the distribution system, including refiners and importers, pipelines, and terminals. Enforcement ends on September 15 at all points in the system, including service stations * Northeast States for Coordinated Air Use management (NESCAUM), which includes Connecticut, Massachusetts, New Jersey, New York, and Rhode Island, implemented the Phase II 9.0 Rvp specification for gasoline beginning June 1, 1989. ** Lower RVP limits apply to the reformulated gasoline through the end of 1997. Production of RFG after 1997 must meet the EPA complex model requirements for reduction in ozone-forming volatile organic compounds during the summer months, and of toxic air pollutants and nitogen oxudes during the entire year. EPA control region 1 (southern U.S.) and region 2 (northern U.S.) only approximately correspond to ASTM region classes.				
Sources:	RVP Phase I gasoline volatility regulation announced by EPA in *Federal Register*, Vol. 54, No. 54 (Washington, DC, March 22, 1989), p. 11868. Phase II gasoline volatility regulation announced in *Federal Register*, Vol. 55, No. 112 (Washington, DC, June 11, 1990), p. 23658. The Phase II regulations were revised to conform to the requirements of the Clean Air Act Amendments of 1990 and announced in *Federal Register*, Vol. 56, No. 239 (Washington, DC, December 12, 1991), p. 64704. RFG program final rule published in *Federal Register*, Vol. 59 No. 32 (Washington, DC, February 16, 1994), p. 7716				

The reduction in allowable RVP affects the supply, demand, and price of motor gasoline. Refiners lower RVP by reducing the volume of high RVP components in motor gasoline, particularly normal butane. Motor gasoline supply is affected because, for a given volume of refinery inputs, less finished motor gasoline is produced. The price of motor gasoline should be higher because normal butane and other low cost blendstocks that have a high RVP must be removed from the motor gasoline pool. Finally, consumer demand for motor gasoline should be lower because reducing motor gasoline RVP improves motor vehicle fuel economy through increases in the motor gasoline energy density (Btu per gallon) and less fuel loss through evaporation.

Net refinery inputs of Butanes have declined by almost 150,000 barrels per day since the start of the RVP Phase I program.

The primary methods refiners have for lowering RVP are reducing the volume of normal butane, a liquefied petroleum gas (LPG), blended into motor gasoline or increasing the volume of normal butane rejected from motor gasoline through distillation. Thus, refiners are expected to reduce *net* refinery inputs of normal butane, which is defined as refinery inputs minus refinery production. About 2 gallons of normal butane must be removed from 100 gallons of motor gasoline to reduce the RVP by 1 pound(s) per square inch (psi) based on a simple linear blending calculation.[(1)] For example, domestic refinery production of motor gasoline averaged about 7.2 million barrels per day during the Phase I RVP controls.[(2)] Lowering average RVP by 1 psi on all domestic motor gasoline production would reduce net refinery inputs of normal butane by up to 140,000 barrels per day (bpd).

Blending of butanes during the summer declined as expected.

EIA surveys show net refinery inputs of butane declined by 80,000 bpd during the Phase I summer RVP control season (April through August 1989, 1990, and 1991) compared with net refinery inputs during the preceding three-year period (Table 2). The Phase II RVP control season (1992-1994) saw an additional reduction in net refinery inputs of normal butane of 55,000 bpd, followed by a more modest decline of 12,000 bpd under the RFG program (1995-1998).

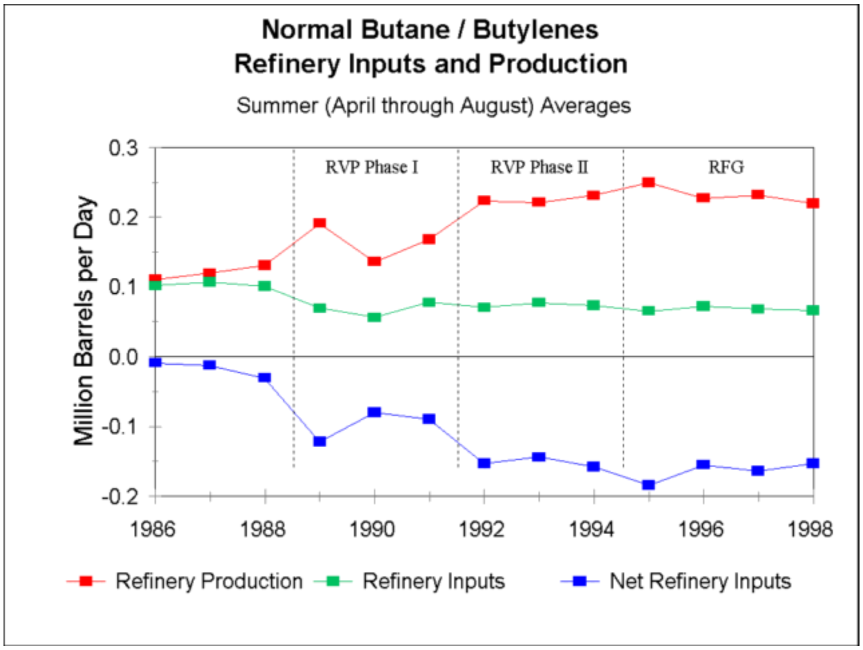
Most of the butanes appears to have found a home in the gasoline pool during the winter.

It is important to note that, while net refinery inputs of normal butane declined significantly during the summer months, there was an increase by over half as much during the winter months (Table 2). Most of the increase (actually a decline in refinery production) was realized during the Phase I RVP controls, possibly because of the sharp drop in butane prices that occurred during this period (discussed later in this report).

Table 2. Refinery Inputs and Production of Normal Butane
(thousand barrels per day)

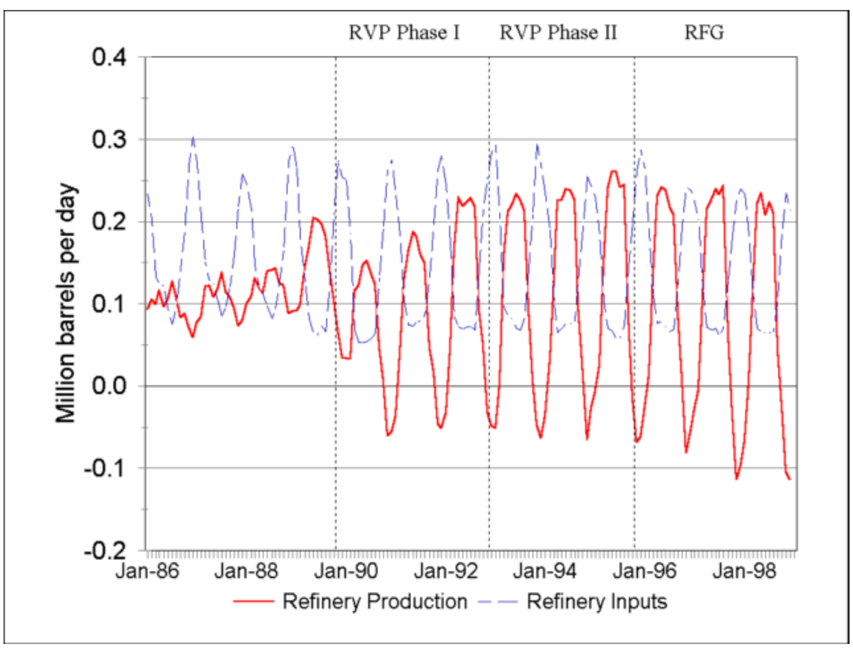
		No RVP Regulations 1986 - 1988 Average	Phase I RVP Controls 1989 - 1991 Average	Phase II RVP Controls 1992 - 1994 Average	Reformulated Gasoline 1995 - 1998 Average
Summer Months					
	Refinery Inputs	103	68	74	68
	Refinery Production	121	165	226	232
	Net Refinery Inputs	**- 17**	**- 97**	**- 152**	**- 164**
Winter Months					
	Refinery Inputs	206	197	203	196
	Refinery Production	97	36	24	- 1
	Net Refinery Inputs	**109**	**161**	**179**	**194**
Notes:	Net Refinery Inputs = Refinery Inputs - Refinery Production Refinery production of low-RVP motor gasoline is assumed to begin one month before the product is required at distribution terminals. Summer average volume is day-weighted average for April 1 through August 31. Winter average volume is day-weighted average for continuous months of September through March (e.g., Sep. 1, 1996 through March 31, 1997).				
Source:	Energy Information Administration, *Petroleum Supply Annual 1998, Volume 2*, DOE/EIA-0340(99)/02 (Washington, DC, June 1999), Table 3, and earlier issues.				

[Download Table Data]



The dramatic change in refinery operations is very evident in a graph of refinery inputs and production of normal butane (Figure 1).

Figure 1. Refinery Inputs and Refinery Production of Normal Butane, January 1986 - December 1998
(millions of barrels per day)



It is not surprising that the observed reduction in net refinery inputs of LPGs during the summer RVP control periods are lower than what is implied by the simple linear vapor pressure blend calculation noted above. First, not all gasoline supply was affected by each regulation. Second, refining cost minimization should also lead to vapor pressure reduction by other means, such as changes in secondary processing unit operating conditions (e.g., catalytic cracking or reforming units) and increasing production of low vapor pressure gasoline blendstocks.

Regression analysis used to measure effect of RVP regulations on butane blending.

While the declines in net refinery inputs of normal butane during the summer months revealed by the survey statistics are consistent with the expected effects of RVP controls, changes in other operating conditions, such as crude oil feed rates or gasoline yields, which may not be related to the environmental regulations, could be responsible. To control for other changes, ordinary least squares regression analyses of refinery inputs and refinery outputs of liquefied petroleum gas (LPG) were made (Appendix Table A1 and Table A2).

Regression results are consistent with survey statistics for Summer RVP controls.

The regression results indicate that changes in net refinery inputs of LPGs during the summer, which can be attributed to the RVP regulations, are consistent with the direction and magnitude of changes in net refinery inputs of normal butane presented above. The estimated coefficients for dummy variables that represent the Summer RVP control seasons indicate the following declines in net refinery inputs of LPGs:

- Phase I RVP control season - net refinery inputs of LPGs declined by 61,200 bpd (refinery inputs of LPGs declined about 18,300 bpd and refinery production increased by 42,900 bpd).
- Phase II RVP control season - net refinery inputs declined by an additional 57,700 bpd (refinery inputs decreased by an additional 3,000 bpd, while refinery production increased by an additional 54,700 bpd in Phase II over Phase I).
- Reformulated gasoline program summer RVP control seasons - an additional 81,200 bpd decline in net refinery inputs.
- The cumulative reduction in net refinery inputs of LPGs during the summer months attributable to the three RVP reduction programs is 200,100 bpd

The regression results reveal a much larger decline in net refinery inputs of LPGs during the reformulated gasoline program than indicated by the survey statistics. The regression results reflect the missing impact of rising crude runs and gasoline production on the LPG balance. In other words, from 1994 to 1998, refinery inputs of crude oil increased by 1.03 million barrels per day and motor gasoline production increased by 0.71 million barrels per day. Regression results indicate that net refinery inputs of LPGs should increase as gasoline production and yields increase, but they declined during the summer months of the RFG program instead. The regression results not only capture the decline in net refinery inputs of LPGs observed in the survey numbers but also the demand from increased motor gasoline production that never materialized.

But, regression results indicate the increase in LPG blending during the winter is not attributable to RVP regulations.

The regression results reveal a different story for the winter months than the simple comparison of normal butane volumes in Table 2. The regression results indicate that changes in net refinery inputs of LPGs during the winter months are not explained by changes in summer RVP requirements. This indicates that other variables included in the regression equations (particularly refinery inputs of crude oil and unfinished oils, and the production of motor gasoline) may account for most of the observed increases in net refinery inputs of LPGs during the winter.

Refinery motor gasoline yields from crude oil and other refinery inputs did not significantly increase during the summer months to make up for the LPGs displaced from the motor gasoline pool.

The removal of normal butane from the summer motor gasoline pool implies an equivalent reduction in the refinery output of motor gasoline for a given volume of refinery inputs, such as crude and unfinished oils. Linear regression of refinery production of motor gasoline against net inputs of LPGs, along with refinery inputs of crude oil and other feedstocks, suggests motor gasoline production declines by 0.88 barrels for each barrel reduction in net refinery inputs of LPGs (Appendix Table A3).

Refiners may increase motor gasoline production (yield) from a given feedslate to make up for the LPGs removed. The estimated coefficients for dummy variables representing the RVP control seasons (summer and winter periods) indicate a small decline in gasoline yield during the years of the RVP Phase I program, a small increase during the Phase II RVP years, and a larger increase since the start of the reformulated gasoline program (Appendix Table A3). However, the estimated coefficients were not statistically significant. Moreover, the increase during the reformulated gasoline program occurred during both the summer and winter months, indicating other unidentified market events were probably influencing gasoline yields during this period. Thus, it appears refiners did not make significant yield adjustments to make up for the reduction in LPGs blended into motor gasoline during the summer. The absence of a significant response (that can be identified by regression analysis) is likely due to the high marginal cost of increasing motor gasoline production in secondary refinery processing units, such as catalytic crackers, that are already run at very high rates and severities in the summer motor gasoline season.

Refinery inputs of crude oil increase to offset the decline in net refinery inputs of LPGs.

Another option refiners have for making up the lost motor gasoline production is to increase crude oil feed rates. Linear regression analysis of refinery inputs of crude oil (controlling for total domestic petroleum product demand and other refinery inputs) suggests that refinery crude oil feed rates increase by about 1.4 barrels for each 1 barrel decline in net refinery inputs of LPGs (Appendix Table A4). Given an estimated yield of 0.42 barrels of motor gasoline from 1 barrel of crude oil (Appendix Table A3), increased refinery crude runs produce about 0.6 barrels of gasoline for each 1 barrel decline in net refinery inputs of LPGs.

The increase in crude oil inputs contributed to the U.S. changing from a net importer of distillate fuel oil to a net exporter.

Coincident with the increase in crude oil runs under the RVP regulations was a dramatic shift in the domestic distillate fuel oil balance. The U.S. went from being a net *importer* of an average 209,000 bpd in 1989 to being a net *exporter* of an average 90,000 bpd by 1993.[3] This trend then reversed with average net *imports* of 85,000 bpd in 1998. The regression analysis cannot identify whether the increase in domestic refinery crude oil inputs and reduction in distillate fuel oil net imports was driven by the reduction of LPGs in the motor gasoline pool or by other factors like an increase in foreign demand for distillate fuel oil, such as in the Far East.

The effect of RVP regulations on motor gasoline imports and inventories cannot be identified.

Two other primary sources of summer motor gasoline supply are imports and inventories. Net imports of motor gasoline steadily declined between 1988, just before the start of the RVP regulations, and 1993. This trend is consistent with the decline in distillate net imports. But the impact of RVP regulations on motor gasoline net imports may not be separable from changes in the international petroleum balance.

Accumulation of finished motor gasoline inventories during the winter heating season may increase to make up for lower summer production under the RVP regulations. The survey data on inventories of finished motor gasoline, gasoline blendstocks, and oxygenates do not reveal any trend in the accumulation of gasoline stocks during the Fall and Winter months. Other market factors appear to have a much greater influence on inventory changes and the association between inventories and RVP regulations cannot be identified.

Normal butane prices were hit hard by the Phase I RVP regulations, then slowly recovered.

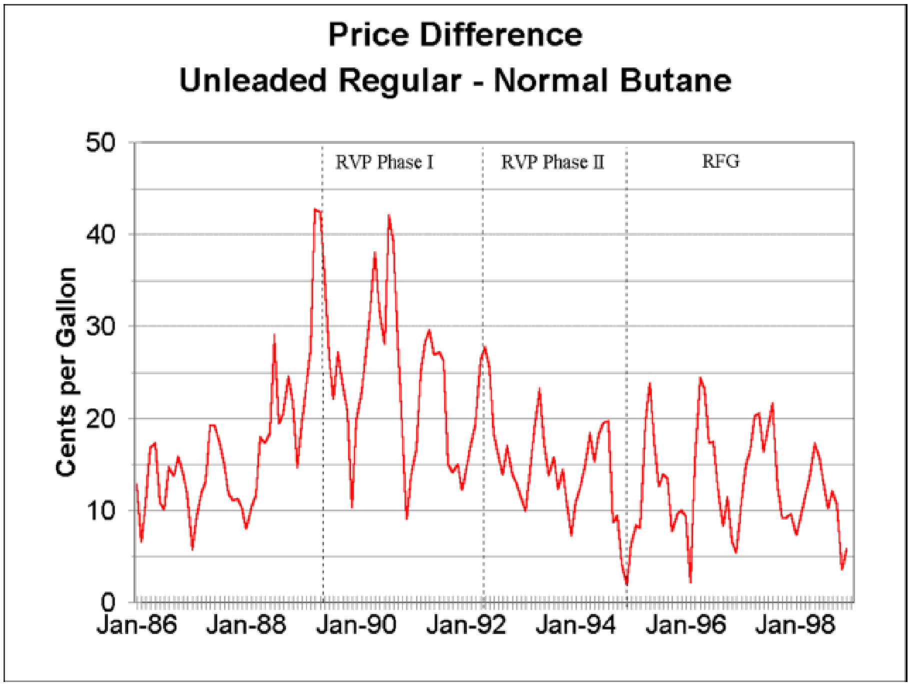
The decline in normal butane demand for motor gasoline blending put downward pressure on butane prices (Table 3). The price of normal butane relative to unleaded gasoline on the U.S. Gulf Coast fell about 5 cents per gallon between 1987 and 1988, one year before the start of the RVP Phase I regulations. Most of the price decline in the butane market occurred during the second half of 1988. The weakness in the butane market was even more dramatic during 1989. While the price of motor gasoline during the Summer of 1989 was about 10 cents per gallon higher than the price during the previous summer, the price of normal butane was almost 4 cents per gallon lower.

Butane prices over the last several years have recovered to their pre-1988 relationship with unleaded gasoline. The oxygenated and reformulated gasoline programs have contributed to the recovery in butane prices because of butane demand for MTBE production. About 0.95 gallons of normal butane are required to produce 1 gallon of MTBE.[4] Domestic MTBE production has increased from 84,000 bpd in 1990 to 205,000 bpd in 1998.[5]

Table 3. Price Relationship Between Normal Butane and Motor Gasoline
(cents per gallon except price ratio)

		No RVP Regulations 1986 - 1988 Average	Phase I RVP Controls 1989 - 1991 Average	Phase II RVP Controls 1992 - 1994 Average	Reformulated Gasoline 1995 - 1998 Average
Summer Months					
	Gasoline Price	48.6	64.6	56.3	55.1
	Normal Butane Price	31.6	32.6	36.7	37.6
	Gasoline-to-Normal Butane Price Comparisons				
	Price Ratio (Gasoline / Butane)	**1.54**	**1.98**	**1.53**	**1.46**
	Price Difference (Gasoline - Butane)	**17.0**	**32.0**	**19.6**	**17.5**
Winter Months					
	Gasoline Price	45.6	62.2	49.1	51.4
	Normal Butane Price	32.8	41.8	37.1	41.9
	Gasoline-to-Normal Butane Price Comparisons				
	Price Ratio (Gasoline / Butane)	**1.39**	**1.49**	**1.32**	**1.23**
	Price Difference (Gasoline - Butane)	**12.8**	**20.4**	**12.0**	**9.5**
Notes:	Gasoline price is U.S. Gulf Coast unleaded 87 octane waterborne spot price. Normal Butane price is Mont Belvieu spot price. Summer average volume is day-weighted average for April 1 through August 31. Winter average volume is day-weighted average for January 1 - March 31 and September 1 - December 31				
Source:	McGraw-Hill, Inc., *Platt's Oilgram Price Report, Price Average Supplement* (New York, NY) various issues.				

[Download Table Data]



Motor gasoline prices increase by about 0.5 cents per gallon for each 1 psi reduction in Reid vapor pressure.

Lowering RVP increases the refiner's cost of producing gasoline because low-cost normal butane must be removed from the gasoline pool. Moreover, if refiners' marginal cost of producing gasoline is an increasing function of motor gasoline yields, then efforts to replace the lost butane volume through higher gasoline yields from refinery inputs should also contribute to higher motor gasoline prices. 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 (April through August) averaged 0.61 cents per gallon, which is equivalent to a price premium of about 0.51 cents per gallon per 1 psi reduction (Table 4).

Table 4. Market Price Premium for Low Vapor Pressure (RVP) Gasoline (cents per gallon)			
	U.S. Gulf Coast Unleaded Regular Waterborne Spot Price		
	9.0 RVP	7.8 RVP	Difference
1993	54.59	55.38	0.79
1994	51.44	52.17	0.73
1995	54.75	55.24	0.49
1995	60.55	60.88	0.33
1997	59.61	60.19	0.58
1998	43.23	43.99	0.76
Note: Averages for period April 1 through August 31 of each year.			
Source: McGraw-Hill, Inc., *Platt's Oilgram Price Report, Price Average Supplement* (New York, NY) various issues.			

[Download Table Data]

Reducing RVP increases motor vehicle fuel efficiency by up to one-half percent.

A reduction in motor gasoline RVP should lead to improved automobile fuel efficiency (on a miles per gallon basis) and lower motor gasoline demand through an increase in motor gasoline energy density (Btu per gallon) and less fuel loss through evaporation.[(6)] A 2 percent reduction in the butane content of motor gasoline may increase energy density and fuel efficiency by as much as 0.43 percent.[(7)] However, estimating the improvement in fuel economy resulting from RVP reductions is problematic because the contribution from fuel quality changes cannot be separated from the general trend of improvement associated with lighter cars and more fuel efficient engines.

Oxygenate Content of Motor Gasoline

The oxygenated gasoline program, mandated by Title II of the Clean Air Act Amendments of 1990, became effective on November 1, 1992. About 12 percent of all motor gasoline sold during the winter months must now contain at least 2.7 percent oxygen by weight in blended oxygenates [(8)] (which is equivalent to 15.2 percent MTBE or 7.6 percent fuel ethanol by volume.)[(9)] The reformulated gasoline (RFG) program, also mandated by the Clean Air Act Amendments of 1990, took effect on January 1, 1995. Under the RFG program, about one-third of all motor gasoline sold throughout the year must contain at least 2.0 percent oxygen by weight (which is equivalent to 11.2 percent MTBE or 5.5 percent fuel ethanol by volume.)

The increase in oxygenate blending into motor gasoline also impacts the supply, demand, and price of motor gasoline. Blending oxygenates increases the volume of motor gasoline product supplied relative to the volumes of other refined products. New supplies of oxygenates from sources other than crude oil (MTBE from natural gas and liquefied petroleum gases; and ethanol from corn) reduce the demand on refinery inputs of crude oil. Motor gasoline prices are higher because of the blending of higher cost oxygenates mandated by the regulations. Motor gasoline demand is also expected to increase because, in contrast to the RVP regulations, the energy content of oxygenated gasoline is lower than that of conventional gasoline.

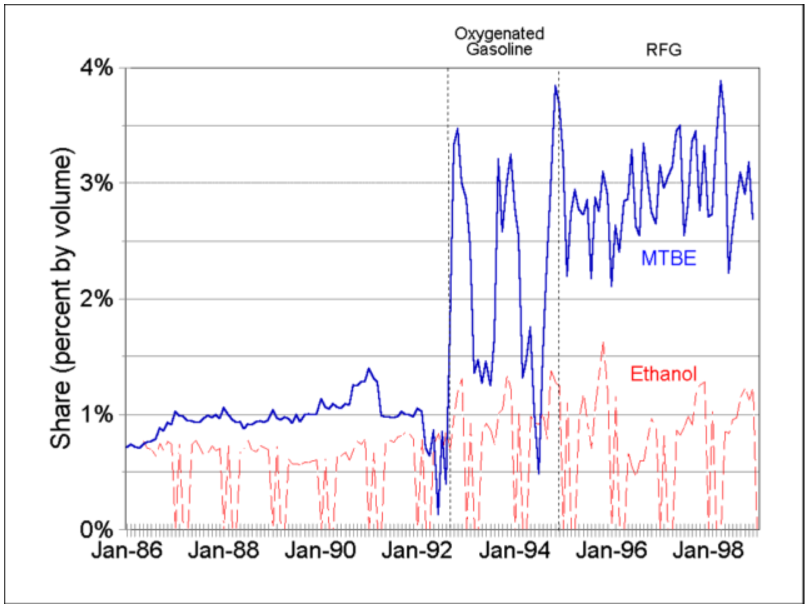
Oxygenate (MTBE and fuel ethanol) blending into motor gasoline has almost tripled in the last 8 years under the oxygenated and reformulated gasoline programs.

MTBE and fuel ethanol usage has grown since the early 1980's in response to octane demand resulting initially from the phaseout of lead from gasoline and later from rising demand for premium gasoline. Federal and local tax incentives for blending renewable fuels into motor gasoline have contributed to the growth in demand for fuel ethanol.

The oxygenated gasoline program stimulated a dramatic increase in fuel ethanol and MTBE production between 1990 and 1994. Ethanol demand for motor gasoline blending increased from an average 49,000 bpd in 1990 to 83,000 bpd in 1994. MTBE demand increased from 83,000 to 161,000 bpd over this same period. Oxygenate blending also exhibited a very strong seasonal component with the winter-only oxygenated gasoline program (Figure 2).

The RFG program provided a further stimulus to oxygenate blending (primarily to MTBE). Blending of MTBE into motor gasoline increased to 251,000 bpd by 1997, while fuel ethanol blending remained flat. The year-round RFG program also smoothed out the seasonality in oxygenate blending (Figure 2).

Figure 2. Oxygenate Content of Motor Gasoline, January 1986 - December 1998
(percent by volume)



Refinery production of motor gasoline increased by just over 1 barrel for each 1 barrel increase in oxygenate blending.

With an increase in refinery inputs of oxygenates, refinery output of motor gasoline may exhibit a larger or smaller increase (for a given volume of other refinery inputs). The change in refinery output of motor gasoline may be smaller than the change in refinery inputs of oxygenates because refiners may cut back on production of other high octane blend components, such as aromatics in secondary processing units (e.g., cat crackers and reformers). However, the reduction of aromatics production may increase motor gasoline yields in these units because the severity of the unit's operating conditions (e.g., temperature, pressure, and reactor space velocity) may be reduced.

Linear regression analysis of refinery production of motor gasoline (Appendix Table A3) indicates that finished gasoline production increased by about 1.5 barrels for each 1 barrel increase in oxygenate blending. However, the simultaneous effects of increased oxygenate blending on refinery inputs of crude oil must also be considered

The increase in the supply of oxygenates derived from non-petroleum sources is expected to reduce demand for crude oil or product imports. However, the offset is likely to be less than 1-for-1. One barrel of MTBE is produced from 0.95 barrels of normal butane (or 0.79 barrels of isobutylene) and 0.34 barrels of methanol. Normal butane is recovered from either crude oil (by distillation and cracking) or natural gas liquids. Methanol is produced from natural gas. If the MTBE feedstocks are obtained from the natural gas market, then either increased natural gas production is required or other hydrocarbons, most likely coming from crude oil, must be substituted. Linear regression analysis of refinery inputs of crude oil (Appendix Table A4) suggests that refinery crude runs declined by 0.74 barrels for each additional barrel of oxygenate blended into motor gasoline ("refinery inputs of other oils"). Since the yield of gasoline from crude oil is about 0.42 (Appendix Table A3), the equivalent drop in motor gasoline production is 0.31 barrels.

The net effect on motor gasoline production of an increase in oxygenate blending comes out to be a 1.2 barrel increase in motor gasoline production for each barrel increase in refinery inputs of oxygenates.

The price premium for oxygenated gasoline is about 3 to 4 cents per gallon over conventional gasoline.

Before the start of the oxygenated gasoline program, the Energy Information Administration originally projected an oxygenated gasoline price premium of 3 to 5 cents per gallon over conventional gasoline. [(10)] The price premium for oxygenated gasoline over conventional gasoline depends on the price of MTBE and fuel ethanol. Oxygenated gasoline requires 2.7 percent oxygen by weight, which is equivalent to about 15.2 volume percent MTBE or 7.6 volume percent fuel ethanol. For example, if the price of MTBE is 20 cents per gallon above the price of conventional gasoline, then oxygenated gasoline with 15.2 volume percent MTBE should have a price premium over conventional gasoline of about 3 cents per gallon (ignoring possible credits for higher octane content and lower vapor pressure of MTBE, and differential blending and shipping costs).

The price premium for oxygenated gasoline over conventional unleaded gasoline during the first two winter control seasons (October 1992 through February 1994) ranged from 3 to 4 cents per gallon (Table 5). During this period the price of MTBE averaged about 24 cents per gallon higher than the price of unleaded regular gasoline. When the price of MTBE increased to over $1.00 per gallon late in 1994 (and the MTBE price premium to 60 cents per gallon), the price premium for oxygenated gasoline rose to over 7 cents per gallon. The MTBE price increase during the second-half of 1994 occurred, not because of an increase demand for oxygenates, but because of a rise in the price of the feedstock methanol, which more than doubled in price as a result of unexpected extended methanol plant outages. While more recent bulk price data for oxygenated gasoline are not available, the winter price premium for MTBE over unleaded regular gasoline has averaged 27 cents per gallon since October 1995 (ranging from 16 to 42 cents per gallon).

Table 5. Oxygenated and Conventional Motor Gasoline Price Relationship
(cents per gallon)

	N.Y. Harbor Cargo			U.S. Gulf Coast Waterborne			
	Conv.	**Oxy.**	**Diff.**	**Conv.**	**Oxy.**	**Diff.**	**MTBE**
Average Oct. 1992 - Feb. 1993	55.1	59.0	**3.9**	53.5	56.8	**3.3**	77.5
Average Oct. 1993 - Feb. 1994	43.8	46.7	**2.9**	42.5	45.7	**3.2**	64.5
Average Oct. 1994 - Dec.1994	49.6	56.5	**7.0**	46.0	53.1	**6.9**	100.1
Notes:	Conv. - Conventional unleaded 87 octane motor gasoline Oxy. - Oxygenated unleaded 87 octane motor gasoline Diff. - Difference between oxygenated and conventional gasoline prices MTBE - U.S. Gulf Coast spot price						
Source:	McGraw-Hill, Inc., *Platt's Oilgram Price Report, Price Average Supplement* (New York, NY) various issues.						

[Download Table Data]

Note: National average or regional prices do not provide valid comparisons of the price differences between conventional gasoline and oxygenated or reformulated gasoline. Oxygenated or reformulated gasoline gasoline is required in areas that traditionally have higher gasoline prices (e.g., urban areas). Thus, when using national average or regional prices, it is important to recognize price differences that existed before the regulated gasolines were required. Because of the difficulty in making this comparison, this report uses refiner bulk prices in the major refining or supply areas (i.e., New York harbor, Gulf Coast, and Los Angeles).

The price premium for reformulated gasoline ranges from 2 to 4 cents per gallon over conventional gasoline.

Before the start of the reformulated gasoline program in 1995, the Energy Information Administration originally projected an RFG price premium of 3.5 to 4 cents per gallon over conventional gasoline. [(11)] The price premium is primarily due to the required 2.0 percent by weight of oxygenates (equivalent to about 11.2 percent MTBE or 5.5 percent fuel ethanol, by volume), which made up 3.0 cents of the projected RFG price premium. The additional requirements for RVP reduction in the summer and reducing 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.

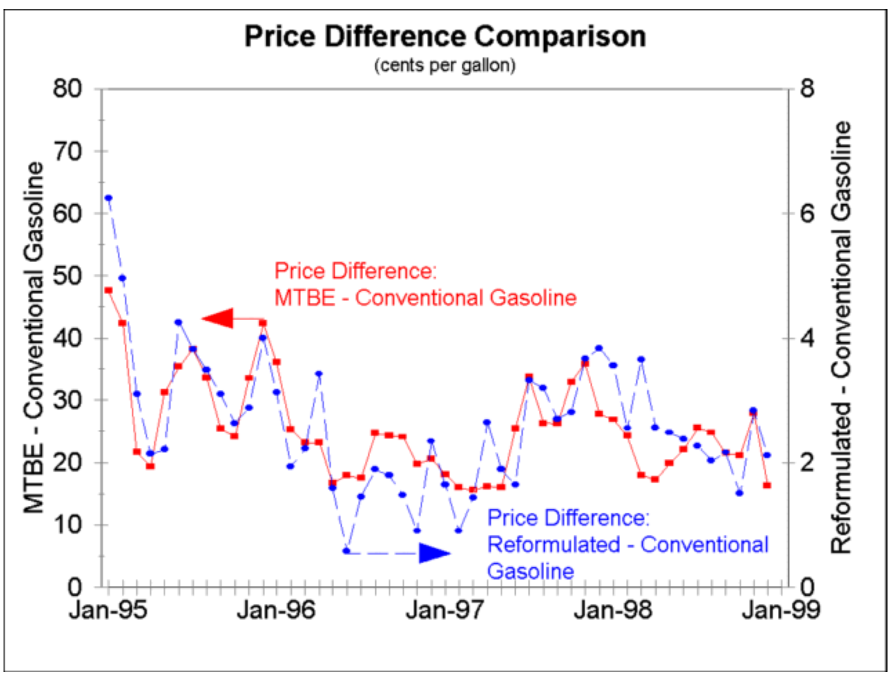
The actual price premium for RFG has generally fallen in the range of 2 to 4 cents per gallon (Table 6). The strong relationship between the cost of MTBE and the price premium for RFG over conventional gasoline is evident from the comparison of price differentials in Figure 3.

Table 6. Reformulated and Conventional Motor Gasoline Price Relationship
(cents per gallon)

	N.Y. Harbor Cargo			U.S. Gulf Coast Waterborne			
	Conv.	**RFG**	**Difference**	**Conv.**	**RFG**	**Difference**	**MTBE**
1995 Average	53.5	56.5	**3.0**	51.0	54.5	**3.5**	83.8
1996 Average	61.0	63.4	**2.4**	60.0	61.9	**1.9**	82.8
1997 Average	59.6	62.2	**2.5**	59.0	61.5	**2.5**	83.2
1998 Average	42.0	43.9	**2.0**	41.8	44.3	**2.5**	63.9
Notes:	Conv. - Conventional unleaded 87 octane motor gasoline RFG - Reformulated unleaded 87 octane motor gasoline Difference - Difference between reformulated and conventional gasoline prices MTBE - U.S. Gulf Coast spot price						
Source:	McGraw-Hill, Inc., *Platt's Oilgram Price Report, Price Average Supplement* (New York, NY) various issues.						

[Download Table Data]

Figure 3. Price Differences Between RFG or MTBE and Conventional Gasoline, January 1995 - December 1998
(cents per gallon)



Oxygenate blending reduces motor vehicle fuel efficiency by 1 to 3 percent.

Motor gasoline demand is expected to increase because of lower automobile fuel efficiency (on a miles per gallon basis) associated with the burning of lower energy-content oxygenates. The energy content of MTBE is about 93,500 Btu per gallon and the energy content of ethanol is 76,000 Btu per gallon, while that of conventional motor gasoline is about 114,000 Btu per gallon.[(12)] The Environmental Protection Agency combined the results of 19 independent studies with more than 4,000 vehicle/fuel tests and found that fuel economy effects depend solely on fuel energy content and that oxygenated gasoline fuel economy is 2 to 3 percent lower than that for conventional gasoline.[(13)] RFG, with a lower oxygenate content and summer RVP, reduces automobile fuel efficiency by about 1 percent during the summer months and 3 percent during the winter.[(14)]

End Notes

(1) Internal calculation based on lowering 11.5 psia vapor pressure finished motor gasoline to 10.5 psia by removing 60 psia normal butane.

(2) Energy Information Administration, *Petroleum Supply Monthly*, DOE/EIA-0109, Table S4.

(3) Energy Information Administration, *Petroleum Supply Monthly*, DOE/EIA-0109, Table S5.

(4) National Petroleum Council, *U.S. Petroleum Refining*, Volume 1 (Washington, DC, August 1993) p. 148.

(5) Energy Information Administration, "Oxygenate Supply/Demand Balances in the Short-Term Integrated Forecasting Model" (March 1998). It should be noted that increased MTBE production *within* refineries can actually reduce butane demand. Isobutylene that is normally reacted with isobutane to form alkylate (a motor gasoline blend stock) may instead be reacted with methanol to produce MTBE, thus reducing isobutane demand in alkylation plants. However, much of the new MTBE capacity built since 1990 obtains isobutylene feedstock from normal butane isomerization/dehydrogenation.

(6) Higher motor gasoline price will also lead to slightly lower demand. The Short-Term price elasticity of demand is about -0.11, so that 1-percent increase in the price of motor gasoline will lead to a 0.11 percent reduction in demand. Energy Information Administration, "Demand, Supply, and Price Outlook for Reformulated Motor Gasoline, 1995" (July 1994).

(7) Based on a simple linear calculation assuming a reduction of normal butane (93,201 Btu per gallon lower heating value) from 5 to 3 volume percent in conventional gasoline (114,000 Btu per gallon lower heating value before butane removal assumed).

(8) This is down from the 30 percent winter market share at the start of the oxygenated gasoline program. The decline resulted from California limiting oxygen content to 2.0 percent by weight and several East Coast cities reaching carbon monoxide attainment and no longer requiring oxygenated gasoline (e.g., Philadelphia and Washington, DC). For reviews of the oxygenated

gasoline program requirements and oxygenate supply and demand issues refer to Energy Information Administration, "Demand, Supply, and Price Outlook for Oxygenated Gasoline," *Short-Term Energy Outlook Annual Supplement 1992*, DOE/EIA-0202(92) (Washington, DC, June 1992), pp. 3-10; "The Economics of the Clean Air Act Amendments of 1990: Review of the 1992-1993 Oxygenated Motor Gasoline Season," *Monthly Energy Review*, DOE/EIA-0380(94/05) (Washington, DC, August 1993); and "Areas Participating in Oxygenated Gasoline Program" (July 1999).

(9) These percentages may change by as much as +/- 0.5 percent absolute (i.e., MTBE in oxygenated gasoline may range from 14.7 to 15.7 volume percent) depending on the density of motor gasoline, the purity of the oxygenate, and the assumed average oxygen content.

(10) Energy Information Administration, "Demand, Supply, and Price Outlook for Oxygenated Gasoline," *Short-Term Energy Outlook Annual Supplement*, DOE/EIA-0202(92) (Washington, DC, June 1992), p. 6.

(11) Energy Information Administration, "Demand, Supply, and Price Outlook for Reformulated Motor Gasoline, 1995" (July 1994).

(12) Energy Information Administration, "Demand, Supply, and Price Outlook for Oxygenated Gasoline," *Short-Term Energy Outlook Annual Supplement*, DOE/EIA-0202(92) (Washington, DC, June 1992), p. 6.

(13) Environmental Protection Agency, "On-Road Study of the Effects of Reformulated Gasoline on Motor Vehicle Fuel Economy in Southeastern Wisconsin," (Washington, DC, March 31, 1994), p. 4. See also, Environmental Protection Agency, Fuel Economy Impact Analysis of RFG

(14) Environmental Protection Agency, Fuel Economy Impact Analysis of RFG

Appendix

Table A1. Refinery Inputs Liquefied Petroleum Gas, LGRIPUS (million barrels per day)								
Equation	**DF Model**	**DF Error**	**SSE**	**MSE**	**Root MSE**	**R-Square**	**Adj R-Sq**	**Durbin-Watson**
LGRIPUS	20	175	0.05806	0.0003318	0.01821	0.942	0.936	1.71
Parameter	**Estimate**	**Approx. Std. Err.**		**'T' Ratio**	**Independent Variable**			
LGRI_B0	0.1164	0.0629		1.85	Constant Coefficient			
LGRI_MG	0.0423	0.0091		4.66	MGROPUS, refinery production motor gasoline			
LGRI_R1	-0.0183	0.0128		-1.43	RVP1 = 1 if April - August, 1989 - 1991; 0 otherwise			
LGRI_R1W	-0.0097	0.0127		-0.76	RVP1W = 1 if September - March, 1989 - 1992 and RVP1=0; 0 otherwise			
LGRI_R2	-0.0213	0.0142		-1.50	RVP2 = 1 if April - August, 1992 - 1994; 0 otherwise			
LGRI_R2W	-0.0212	0.0143		-1.49	RVP2W = 1 if September - March, 1992 - 1995 and RVP2=0; 0 otherwise			
LGRI_R3	-0.0800	0.0156		-5.12	RVP3 = 1 if April - August, 1995 and later years; 0 otherwise			
LGRI_R3W	-0.0606	0.0154		-3.93	RVP3W = 1 if September 1995 or later and RVP3=0; 0 otherwise			
LGRIPUS_L1	0.7396	0.0526		14.1	1st-order autocorrelation correction parameter			
Method of estimation: OLS with 1st-order autocorrelation correction Estimation period: January 1983 through March 1999 Estimated coefficients for monthly dummy variables are not reported here								

Table A2. Refinery Output Liquefied Petroleum Gas, LGROPUSX (million barrels per day)								
Equation	**DF Model**	**DF Error**	**SSE**	**MSE**	**Root MSE**	**R-Square**	**Adj R-Sq**	**Durbin-Watson**
LGROPUSX	23	172	0.13381	0.0007780	0.02789	0.969	0.965	1.90

Parameter	**Estimate**	**Approx. Std. Err.**	**'T' Ratio**	**Independent Variable**
LGRO_B0	-0.1093	0.1986	-0.55	Constant Coefficient
LGRO_MG	-0.6788	0.3355	-2.02	MGYLD, refinery yield of motor gasoline
LGRO_C1	0.0489	0.0087	5.59	CORIPUS, refinery inputs crude oil
LGRO_C2	0.0586	0.0164	3.57	UORIPUS, refinery inputs unfinished oils
LGRO_R1	0.0429	0.0233	1.84	RVP1 = 1 if April - August, 1989 - 1991; 0 otherwise
LGRO_R1W	0.0014	0.0235	0.06	RVP1W = 1 if September - March, 1989 - 1992 and RVP1=0; 0 otherwise
LGRO_R2	0.0976	0.0338	2.89	RVP2 = 1 if April - August, 1992 - 1994; 0 otherwise
LGRO_R2W	-0.0088	0.0340	-0.26	RVP2W = 1 if September - March, 1992 - 1995 and RVP2=0; 0 otherwise
LGRO_R3	0.1201	0.0447	2.69	RVP3 = 1 if April - August, 1995 and later years; 0 otherwise
LGRO_R3W	-0.0204	0.0446	-0.46	RVP3W = 1 if September 1995 or later and RVP3=0; 0 otherwise
LGRO_T	0.00090	0.00037	2.39	TIME = 1 to n, where n = number of observation
LGROPUSX_L1	0.6832	0.0599	11.4	1st-order autocorrelation correction parameter

Method of estimation: OLS with 1st-order autocorrelation correction
Estimation period: January 1983 through March 1999
Estimated coefficients for monthly dummy variables are not reported here

Table A3. Refinery Output Motor Gasoline, MGROPUSX (million barrels per day)								
Equation	**DF Model**	**DF Error**	**SSE**	**MSE**	**Root MSE**	**R-Square**	**Adj R-Sq**	**Durbin-Watson**
MGROPUSX	27	168	0.71076	0.004231	0.06504	0.986	0.984	1.99

Parameter	**Estimate**	**Approx. Std. Err.**	**'T' Ratio**	**Independent Variable**
MGRO_B0	0.7843	0.3962	1.98	Constant Coefficient
MGRO_PR	0.0183	0.00213	8.59	(MGWHUUSX-D2WHUUS)/WPCPIUS, deflated price differential between motor gasoline and distillate fuel
MGRO_C1	0.4163	0.0200	20.8	CORIPUS, refinery inputs crude oil
MGRO_C2	0.5207	0.0408	12.8	UORIPUS, refinery inputs unfinished oils
MGRO_C3	0.6287	0.0850	7.40	MBRIPUS, refinery inputs motor gasoline blend components
MGRO_C4	1.4855	0.2202	5.71	OXRIPUS, refinery inputs oxygenates
MGRO_C5	0.8850	0.1383	6.16	(LGRIPUS - LGROPUS), net refinery inputs of LPGs
MGRO_C6	0.8321	0.4319	1.93	PPRIPUS, refinery inputs pentanes plus
MGRO_PS	0.000505	0.00112	0.45	lag(MGPSPUSA), beginning-of-month deseasonalized motor gasoline stocks
MGRO_R1	-0.0479	0.0421	-1.14	RVP1 = 1 if April - August, 1989 - 1991; 0 otherwise
MGRO_R1W	0.0183	0.0389	0.47	RVP1W = 1 if September - March, 1989 - 1992 and RVP1=0; 0 otherwises
MGRO_R2	0.0152	0.0539	0.28	RVP2 = 1 if April - August, 1992 - 1994; 0 otherwise
MGRO_R2W	0.0309	0.0576	0.54	RVP2W = 1 if September - March, 1992 - 1995 and RVP2=0; 0 otherwise
MGRO_R3	0.1307	0.0921	1.42	RVP3 = 1 if April - August, 1995 and later years; 0 otherwise
MGRO_R3W	0.1091	0.0809	1.35	RVP3W = 1 if September 1995 or later and RVP3=0; 0 otherwise
MGROPUSX_L1	0.5846	0.0693	8.44	1st-order autocorrelation correction parameter

Method of estimation: OLS with 1st-order autocorrelation correction
Estimation period: January 1983 through March 1999
Estimated coefficients for monthly dummy variables are not reported here

Table A4. Refinery Inputs Crude Oil, CORIPUSX (million barrels per day)								
Equation	**DF Model**	**DF Error**	**SSE**	**MSE**	**Root MSE**	**R-Square**	**Adj R-Sq**	**Durbin-Watson**
CORIPUSX	22	173	8.25008	0.04769	0.21838	0.957	0.952	2.11
Parameter	**Estimate**	**Approx. Std. Err.**		**'T' Ratio**	**Independent Variable**			
COR_B0	11.1807	1.6137		6.93	CORIPUS Constant Coefficient			
COR_PATC	0.2160	0.0347		6.22	PATCPUSX, total petroleum product demand			
COR_PAT1	0.2287	0.0463		4.94	LAG(PATCPUSX), 1-month lag total petroleum product demand			
COR_MGPS	-0.0157	0.00398		-3.95	LAG(MGPSPUSA), 1-month lag end-of-month deseaonalized motor gasoline stocks			
COR_MGP1	-0.0122	0.00337		-3.60	LAG2(MGPSPUSA), 2-month lag end-of-month deseaonalized motor gasoline stocks			
COR_DFPS	0.00258	0.00401		0.64	LAG(DFPSPUSA), 1-month lag end-of-month deseaonalized distillate fuel stocks			
COR_DFP1	-0.00869	0.00367		-2.37	LAG2(DFPSPUSA), 2-month lag end-of-month deseaonalized distillate fuel stocks			
COR_UORI	-0.2762	0.1266		-2.18	UORIPUS, refinery inputs unfinished oils			
COR_LGRI	-1.4327	0.3354		-4.27	(LGRIPUS-LGROPUS), refinery net inputs LPGs			
COR_PSRI	-0.7384	0.2365		-3.12	PSRIPUS, refinery inputs other oils			
CORIPUSX_L1	0.7151	0.0660		10.8	1st-order autocorrelation correction parameter			
Method of estimation: OLS with 1st-order autocorrelation correction Estimation period: January 1983 through March 1999 Estimated coefficients for monthly dummy variables are not reported here								

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