

# Ethanol Demand in U.S. Gasoline Production

Office of Fuels Development, U.S. Department of Energy

May 1999

For additional information, contact Tien Nguyen at (202) 586-7387

**David Andress**

**David Andress & Associates, Inc.**

**Gerald R Hadder**

**Center for Transportation Analysis  
Oak Ridge National Laboratory**

## *Introduction*

The Energy Policy Act (EPAAct) of 1992 outlined a national energy strategy to reduce the nation's growing dependence on imported petroleum. Recognizing the need to develop alternative transportation fuels, the Act directed the Secretary of Energy to establish a program to promote and expand the use of fuels derived from renewable resources. The Office of Transportation Technologies (OTT) within the Department of Energy (DOE) has evaluated a wide range of potential fuels and has concluded that cellulosic ethanol is one of the most promising near-term prospects. Ethanol is a proven and publicly accepted fuel that has been used in the United States since the 1970s. It is widely recognized as a clean fuel that helps reduce emissions of toxic air pollutants. Furthermore, cellulosic ethanol produces less greenhouse gas emissions than gasoline, or for that matter, any of the other alternative transportation fuels being promoted for development by DOE.

About 1.5 billion gallons of ethanol per year are currently used in gasoline blends. Most of this ethanol now comes from corn. While some growth in the corn-based ethanol industry is anticipated, its expansion is constrained by the competing uses of corn as a food crop. DOE believes that cellulosic ethanol technology has the potential to significantly increase domestic ethanol production and is currently funding research to advance cellulosic ethanol conversion techniques. Cellulosic ethanol can be produced from agricultural residues and genetically engineered biocrops specifically designed for the energy market.

## *Ethanol Markets*

Ethanol has the potential to displace petroleum in two distinct markets. The "blend" market is characterized by gasoline/ethanol mixtures containing 10 percent or less ethanol by volume. The

"neat" market is characterized by ethanol/gasoline mixtures containing 85 percent or more ethanol by volume.

The majority of ethanol's growth in the near future will come in the blend market, owing to several significant advantages blends have in comparison to neat fuels. First, gasoline/ethanol blends can be used in all automobiles and light trucks on the road today. Neat ethanol fuels require specially adapted engines and can be used in only a small percent of the current vehicle fleet. Second, ethanol blends are compatible with the existing service station infrastructure. Because of the need for separate service station tanks and pumps, neat ethanol fuels will require substantial infrastructure investments. Third, ethanol used in blends has an economic value as an octane enhancer and oxygenate. Neat fuels are viewed as alternatives to gasoline and will have to compete on a mileage or energy-content basis. Ethanol is disadvantage here as the energy content of a gallon of ethanol is only about two-thirds that of a gallon of gasoline.

### ***Demand for Ethanol in the U.S. Gasoline Blend Market***

The Oak Ridge National Laboratory Refinery Yield Model (ORNL-RYM) was used to quantify the relationship between the price the refiner pays for ethanol and the demand for ethanol. ORNL-RYM identifies opportunities for using ethanol and ethanol-based ethers in gasoline production in the overall refinery production process, while accounting for competition from gasoline and oxygenates such as methyl tertiary butyl ether (MTBE). A recently completed ORNL study<sup>1</sup> produced several important findings:

- Demand for ethanol use in gasoline blends could be substantial as the price of ethanol decreases relative to gasoline
- Ethanol demand varies with gasoline type. In particular, ethanol demand is greater with a lower share of reformulated gasoline (RFG) in the gasoline pool.
- Regional and seasonal variations in ethanol demand are significant and must be considered in any comprehensive ethanol market analysis.
- Changes in gasoline specifications, such as low sulfur gasoline or an MTBE ban, can further increase ethanol demand.

---

<sup>1</sup> Hadder, G.R., 1998, *Ethanol Demand in United States Gasoline Production*, ORNL-6926, Oak Ridge National Laboratory, Oak Ridge, TN

## ***A Brief Primer on Gasoline***

The gasoline used in the United States today can be loosely grouped into three categories: conventional gasoline (CG), reformulated gasoline (RFG), and oxygenated gasoline. The Clean Air Act Amendments (CAAA) of 1990, which established a regulatory framework for improving the nation's air quality, introduced requirements for using RFG and oxygenated fuels. RFG must be used in areas with extreme or serious summer ozone non-attainment problems and may be used in areas with moderate or marginal ozone non-attainment problems. Oxygenated fuels, which are gasolines containing a minimum oxygen concentration of 2.7 weight percent, must be used in winter carbon-monoxide non-attainment areas. The CG category consists of gasolines which are not classified as RFG (or an RFG blendstock) or oxygenated gasoline. The CG category includes conventional gasoline/ethanol blends, commonly called gasohol. The CAAA requires CG to have no increase in pollutant emissions relative to a base year.

### **Oxygen Requirements**

Both RFG and oxygenated gasoline must contain a specified oxygen concentration, but RFG must also meet a comprehensive set of specifications designed to reduce emissions of certain air pollutants. The minimum oxygen concentration for Federal RFG is 2.0 weight percent. California, because of its unique air quality problems, has its own RFG specification, known as California or CARB RFG. Oxygenated gasoline is typically a blend of conventional gasoline and a fuel oxygenate. Most oxygenate requirements today are satisfied by ethanol and MTBE. CG does not have an oxygen content requirement, but can be blended with an oxygenate such as ethanol. This can make the classification of gasoline containing an oxygenate confusing – the distinction is based on whether or not a minimum oxygen content is required by a CAAA mandate.

Ethanol/gasoline blends are limited to a maximum of 10 percent ethanol by volume. This corresponds to an oxygen concentration of about 3.5 weight-percent. Gasoline containing ethers, such as MTBE or ethyl tertiary butyl ether (ETBE), are limited to a 2.7 weight-percent oxygen concentration. This corresponds to 15 percent MTBE or 17.2 percent ETBE (7.7 percent ethanol), by volume.

### **Ozone Formation and Gasoline Volatility**

Ozone results from photochemical reactions with certain organic and nitrogen compounds contained in fuel evaporative and tailpipe emissions. Because the rate at which the reactions proceed is related to both temperature and sunlight intensity, ozone problems are greater in the summer than in the winter. As ozone is only problematic in the summer, only summer gasoline is regulated for ozone control.

Evaporative emissions of volatile organic compounds (VOC) are related to gasoline vapor pressure, which is measured in units of Reid vapor pressure (RVP). The RVP of a gasoline mixture depends on which fuels are blended with the gasoline. Even though pure ethanol has an RVP lower than that

of gasoline, the RVP of ethanol blends (low volume percent of ethanol) is higher than that of pure gasoline. The RVP of ether blends (low volume percent of ether) can be lower than that of pure gasoline.

Summer CG has an average RVP of around 9 psi. (RVP regulatory limits differ from northern to southern regions). CG containing 10 volume-percent ethanol is granted a one-psi waiver from the CG RVP specifications. This is the approximate RVP increase of a 10 percent ethanol blend. Phase II RFG, scheduled for retail distribution beginning January 1, 2000, is controlled for VOC emissions. Refiners have some leeway in formulating gasoline to meet Phase II reduced VOC emission reductions, but most analysts believe they will need to produce a gasoline with an RVP of roughly 7-psi. The RVP waiver does not apply to RFG/ethanol blends.

## **Octane**

Both ethanol and ethers, such as MTBE and ETBE, have higher octane ratings than gasoline. The octane boost to gasoline from adding ethanol and ethers allows the refiner to produce a lower octane, less expensive base gasoline for blending. This has proved especially valuable in producing clean gasoline, since these oxygenates can replace some of the higher-octane components of gasoline that produce undesirable levels of toxic air pollutants. In practice, ethanol is frequently mixed with regular CG to produce a mid-grade or premium gasoline.

## **Logistics and Handling**

Because ethanol is soluble in water and gasoline/ethanol blends will separate into phases at low levels of water contamination, precautions have to be taken to guard against water incursion. As a result, most ethanol used in gasoline blends is blended at distribution terminals located near retail distribution points, a process called splash blending. The ethanol used for blending is usually shipped by rail or truck, and not in common-carrier pipelines which typically contain some moisture. This process adds an extra logistics and handling costs to using ethanol blends. Gasoline/ether blends do not phase separate in the presence of water and are compatible with the standard gasoline distribution system.

## ***Overview of ORNL-RYM***

ORNL-RYM is an enhanced personal computer version of the Refinery Yield Model of the U.S. Department of Energy (DOE) Refinery Evaluation Modeling System. ORNL-RYM is a linear program that includes 50 refining processes, which fall within three general categories:

- Separation – e.g., crude oil is separated into fractions by distillation
- Conversion – e.g., molecules are cracked, combined, rearranged
- Blending – separated and converted streams are mixed to make products that satisfy numerous quality specifications.

The refining processes in ORNL-RYM can simulate the production of 40 different products from more than 100 crude oils. A capital investment feature of ORNL-RYM provides for the addition of processing capacity. The model blends gasolines to comply with formula and pollutant emission standards mandated by the Clean Air Act Amendments and described by the U.S. Environmental Protection Agency (EPA) Complex Model, which predicts pollutant emissions in terms of gasoline properties. Modeled gasolines satisfy specifications for octane, RVP, oxygen content, sulfur, benzene, aromatics, total olefins, distillation points, and pollutant emissions.

## ***Ethanol Demand Analysis***

Scientists at Oak Ridge National Laboratory used ORNL-RYM to analyze the refinery/gasoline blender demand for ethanol in gasoline blends. The analysis was based on many specific premises; three of the most important assumptions are listed below:

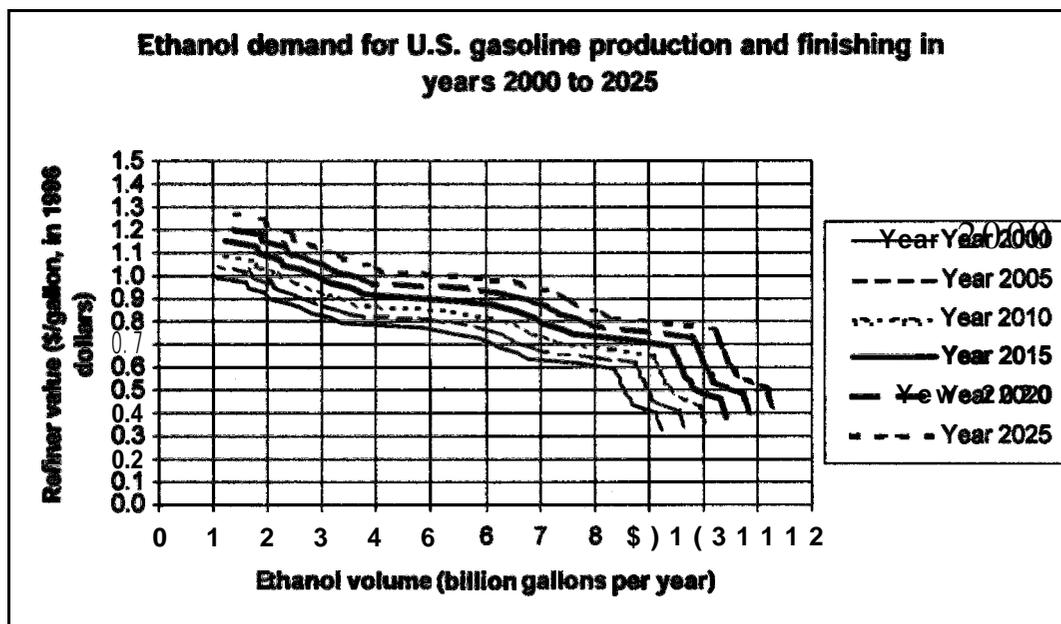
- Gasoline blending is optimized, with minimum giveaway of gasoline quality. Modeled refineries can produce subgrade gasolines for shipment to blenders who add optimal volumes of ethanol to produce finished gasoline.
- There are no infrastructure barriers to using ethanol and consumers are indifferent to ethanol blends.
- The ethanol handling and logistics costs incurred by the refiner/blender are \$0.10 per gallon of ethanol.

## **National Ethanol Demand**

The ORNL-RYM analysis developed a set of ethanol demand curves that relate the refiner value of ethanol to the refiner demand for ethanol by systematically varying ethanol prices to determine the refiner demand for ethanol at each price level. The refiner value of ethanol is net of any tax incentives, i.e., it is the producer price of ethanol less the value of the tax incentives. Currently, the Federal excise tax exemption for ethanol used in gasoline blends is equivalent to 54 cents per gallon of ethanol. Some states also grant ethanol tax incentives.

Regional demand curves were produced for individual Petroleum Allocation for Defense Districts (PADD) for the year 2010 and aggregated to a national level. The analysis used the reference world oil prices (\$24.77 per barrel in 2010 in 1996 dollars) from the Annual Energy Outlook (AEO) published by the Energy Information Administration (EIA). The national ethanol demand curve for year 2010 was extrapolated to demand curves for five-year intervals between the years 2000 and 2025, as shown in the figure.

The figure indicates that the future demand for ethanol by gasoline producers could be substantial as the refiner/blender value of ethanol decreases relative to the value of gasoline. For example, the ethanol demand in year 2010 is 2 billion gallons per year (BGY) at a refiner value of \$1.00 per gallon (1996 dollars), and 9 BGY at a refiner value of \$0.60 per gallon. On the right end of the curves,



demand increases slowly with decreasing refiner values of ethanol, because gasolines are approaching the maximum allowable oxygen content and the more valuable properties of ethanol have been exploited. The demand curves are extremely useful in helping DOE establish cost targets for ethanol production technology and in assessing government policy options.

### **Ethanol Demand is Greater with a Smaller Share of RFG in the Gasoline Pool**

Because reformulated gasoline must contain oxygen, it was originally thought that a larger RFG program would increase the demand for ethanol. The ORNL refinery analysis, however, found just the opposite to be true; i.e., the demand for ethanol is greater with a smaller share of RFG in the gasoline pool. Summer RFG must have reduced VOC emissions, which can be more expensive to satisfy with high RVP-blending components like ethanol, because of the need to produce a lower-RVP subgrade gasoline for ethanol blending. Alternatively, ethanol can be converted into ETBE to eliminate the need for a lower-RVP subgrade gasoline, but there is a cost associated with the conversion. In either case, the additional processing costs make it difficult for ethanol to compete with MTBE in summer RFG. On the other hand, ethanol is more competitive in summer CG because the one-psi RVP waiver for CG blends containing 10-percent ethanol eliminates the need for producing a lower-RVP subgrade gasoline.

Winter gasoline is not VOC controlled and ethanol is not disadvantaged by RVP considerations. The ORNL-RYM analysis showed winter ethanol demand increases with a larger share of RFG in the gasoline pool. However, Federal regulations do not allow RFG use to be varied by season. When the combined effect of summer and winter gasolines are taken into account, the conclusion is that overall ethanol demand is greater with a smaller share of RFG in the gasoline pool. The increase in

winter ethanol demand must be interpreted within the context of the study premises, which assumed no infrastructure barriers. For operational reasons, refiners are reluctant to switch between the use of ethanol and MTBE in RFG according to season.

On the other hand, ethanol competes well with MTBE in winter oxygenated fuels required in carbon monoxide nonattainment areas. On a volume basis, ethanol has about twice the oxygen content as MTBE, so only about half as much gasoline is displaced with ethanol to satisfy the CAAA oxygen content requirement.

## *Regional Ethanol Demand*

The national demand curves are useful for aggregate policy and market analyses. For a more detailed analysis of an emerging cellulosic ethanol industry, accurately characterizing regional ethanol demand is important. Ethanol production facilities must be located near feedstock sources due to the high cost of transporting biomass feedstocks. And because ethanol transportation costs are higher than those of gasoline, most ethanol is currently consumed near where it is produced. A detailed regional analysis of ethanol markets has to explicitly account for region-specific transportation costs and tax incentives and the ORNL-RYM regional demand curves can be modified to include these factors.

Detailed ORNL-RYM runs were made for PADD I (East Coast), PADD II (Midwest), PADD III (Gulf Coast), and PADD VC (California), for both summer and winter conditions. These runs cover about 93 percent of the U.S. refining capacity. For reporting purposes, the RFG category included oxygenated fuel requirements. The RFG share of the gasoline pool and the percent of U.S. production for each PADD, along with the ethanol demand in 2010 at 60 and 90 cents per gallon, are listed below.

<i>PADD</i>	<i>RFG Production Share (percent)</i>	<i>Percent of U.S. Refinery Production</i>	<i>Ethanol Demand (Billion of Gallons per Year)</i>	
			<i>60 cents per gallon</i>	<i>90 cents per gallon</i>
<i>I (East Coast)</i>	61	11	1.0	0.8
<i>II (Midwest)</i>	12	24	2.6	0.7
<i>III (Gulf Coast)</i>	18	45	4.2	1.3
<i>IV (California)</i>	86	13	0.9	0.5
<i>Total</i>		93	8.7	3.3

*Ethanol demand for 2010 case. Ethanol prices (1996 dollars) to the refiner are net of any tax incentives*

When ethanol prices are low, e.g., 60 cents per gallon, ethanol demand is greatest in PADDs II and III because of their large share of the total U.S. gasoline production (69 percent total) and their small share of RFG production. This is an important observation since most of the areas identified for potential low-cost biomass residues and/or dedicated bio-energy crops are in these regions. When

ethanol prices are high, e.g., 90 cents per gallon, ethanol demand variation among PADDs is less pronounced. PADD III has the highest demand because of its large share of gasoline production (45 percent). However, demand in PADDs I and II is roughly equal, despite the fact that gasoline production in PADD II is more than twice that of PADD I. The higher relative demand in PADD I occurs because gasoline and some refinery inputs are relatively more expensive in that region.

## ***Changes in Gasoline Specifications***

The ORNL-RYM runs were made within the context of the current regulatory environment. However, regulations are continuously evolving and several sensitivity analyses were made to determine how ethanol demand would respond to changes in gasoline specifications. Of all the cases analyzed, the specification changes that appear most likely are for low-sulfur gasoline and restrictions on the use of MTBE.

### **Sulfur Reduction in Gasoline**

EPA believes that reduction of sulfur in gasoline may be required to enable the use of advanced vehicle pollution control technologies. According to car makers, sulfur competes for the same trap points in catalytic converters that capture toxic air pollutants. EPA recently announced a proposal for a nationwide average sulfur content of 30 parts per million to be phased in between 2004 and 2006. The nationwide average is now about 330 parts per million.

Prior to the EPA announcement, ORNL-RYM was used to estimate summer ethanol demand for a Midwest refinery case that assumed 100 percent low sulfur gasoline (LSG) production, where the sulfur content was set at 100 parts per million. ORNL-RYM shows that a requirement for LSG substantially increases the demand for ethanol over a significant range of refiner values for ethanol. The increase in ethanol demand is due, in part, to its contribution in sulfur reduction through dilution and to the recovery of lost octane. In conventional hydrocarbon processing, there is a loss of octane in the reduction of sulfur (through saturation of olefins).

### **MTBE and Water Quality**

MTBE imparts a disagreeable taste and odor to water at extremely low concentrations and some contamination of drinking water has been reported. Leaching from leaking underground fuel tanks causes most MTBE contamination in ground water. While the number of confirmed incidents is small, they are taken quite seriously by Federal and state regulatory authorities. The U.S. Environmental Protection Agency (EPA) has assembled a blue-ribbon advisory group to investigate this matter. The state of California and other entities, such as the Northeastern States, have also initiated studies related to ether issues.

On March 25, 1999, Governor Gray Davis announced that MTBE could not be used in California gasoline after 2002. The Governor concluded that MTBE posed an environmental and water quality

threat. The time frame was chosen to allow an orderly transition to alternative gasoline formulations that would maintain air quality standards. Whether the rest of the nation will follow California's lead is not known at this time.

Currently, the only two oxygenates in widespread use are ethanol and MTBE. If MTBE is banned, this would clearly present an opportunity for ethanol. Several studies looked at the cost and feasibility of producing RFG with ethanol as the sole oxygenate and concluded that, over the long term, the increase in cost would be small provided sufficient quantities of ethanol are available.

One course of action California is pursuing is to seek Federal relief from the RFG oxygenate requirements, which most observers believe would require amending the Clean Air Act. Even if the oxygenate requirement for RFG were removed, several studies have indicated that some use of oxygenates would still be cost effective in meeting gasoline emission requirements.

At this point in time the whole issue of gasoline formulation is in the process of being reviewed by both government agencies and the private sector. Regulatory changes concerning ether use and oxygenate requirements can have a dramatic effect on ethanol demand.