United States General Accounting Office

GAO

Report to the Honorable Tom Daschle, U.S. Senate

June 1996

MOTOR FUELS

Issues Related to Reformulated Gasoline, Oxygenated Fuels, and Biofuels

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General Accounting Office
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Resources, Community, and
Economic Development Division

B-271630

June 27, 1996

The Honorable Tom Daschle
United States Senate

Dear Senator Daschle:

The use of reformulated gasoline is now required in those areas of the United States with the most severe ozone air pollution. As part of the reformulation process, oxygenates, such as methyl tertiary butyl ether, or ethanol, are added to gasoline to enhance combustion and reduce the emissions that cause ground level ozone problems as well as reduce air toxics emissions. Oxygenates are also sometimes added to gasoline to increase octane levels, and according to the Department of Energy (DOE), oxygenates can also help reduce our growing need for petroleum.

According to DOE, biofuels—primarily ethanol developed from corn or from biomass such as fast-growing trees or grasses—also have the potential to reduce air pollution and the demand for petroleum. Such ethanol can be used as an oxygenate or, in its pure or near-pure form, as an alternative transportation fuel.

This report responds to your request that we summarize (1) the results of federal and other studies on the cost-effectiveness of using reformulated gasoline compared to other measures to control automotive emissions and compare the price estimates used in the studies for reformulated gasoline with more recent actual prices; (2) the results of studies estimating the potential for oxygenates to reduce the use of petroleum; and (3) the ongoing federal research into biofuels, including any related past or projected cost-reduction goals, and any increased demand estimates based on such research goals.[1] You also requested that we summarize the results of studies that estimate the potential for reformulated gasoline to reduce greenhouse gas emissions compared to conventional gasoline. (See app. I for information on the greenhouse gas emission characteristics of reformulated gasoline.)

Results in Brief

Studies by the Environmental Protection Agency (EPA), the American Petroleum Institute, and others suggest that reformulated gasoline may be cost-effective compared to some automotive emission control measures

[1]In responding to your request, we previously provided a report, requested by Senator Grassley, on the possible effects of eliminating the current tax exemption for ethanol (GAO/RCED-95-273R, Sept. 14, 1995), and we briefed your staff on the tax expenditures associated with oil and gas and biofuels.

but less cost-effective than other measures.[2] Other emission control measures contained in the studies include automobile emission inspection and maintenance programs, on-board automobile emission diagnostic equipment, and refueling vapor recovery equipment at service stations. The methodologies used and the results showing the cost-effectiveness of the control measures for these studies vary significantly, making comparisons very difficult. The extent and nature of air pollution in any specific area and the pollution control measures already in use will have a large bearing on what specific control measures are the most cost-effective and whether they should be used either individually or in some combination. The price estimates for reformulated gasoline used in the studies also varied but were generally consistent with the prices actually experienced to date.

About 305,000 barrels per day of the petroleum used to produce gasoline will be potentially displaced by oxygenates in the year 2000 and about 311,000 barrels per day in 2010, according to the DOE Energy Information Administration's projected oxygenate use. This petroleum displacement amounts to about 3.7 percent of the estimated gasoline consumption in 2000 and 3.6 percent in 2010.[3]

DOE and the U.S. Department of Agriculture (USDA) are the primary federal agencies with ongoing research into biofuels. DOE is focusing primarily on reducing the cost of growing and converting biomass feedstocks, such as trees and grasses, into ethanol. USDA is focusing primarily on reducing the cost of growing and converting agricultural feedstocks, such as corn, into ethanol. DOE's and USDA's data indicate that research has reduced the cost of producing ethanol from both cellulosic biomass and from corn.[4] Further cost reductions in producing ethanol from corn, and subsequent increases in the demand for corn-based ethanol, may be constrained by the price of corn and its use for other purposes. DOE believes that the demand for ethanol made from cellulosic biomass for use as an oxygenate and as an alternative fuel could increase significantly, assuming the successful development and commercialization of biofuels technologies and the achievement of the agency's cost-reduction goals.

[2]For this report, cost-effectiveness is used as a comparative measure between various pollution control options, taking into consideration such factors as the cost to implement the option and its effectiveness in reducing pollution.

[3]To the extent petroleum is used to make oxygenates, these figures would be lower.

[4]Cellulosic biomass represents the major portion of plant matter, such as wood, grass, organic wastes, and agricultural residues.

Background

The 1990 amendments to the Clean Air Act require the use of reformulated gasoline (RFG) in nine areas of the United States with severe ozone pollution. The act set up a two-phase program. Under phase I, beginning in January 1, 1995, volatile organic emissions and toxic air pollutants are to be reduced by 15 percent. During phase II of the RFG program, to start in the year 2000, EPA's rules require reductions of 5.5 percent of nitrogen oxides along with further reductions in volatile organic and toxic emissions.[5] As an emission control measure, areas that have less severe ozone problems but that still exceed the standards may also use RFG to reduce pollution problems.[6]

Oxygenates are compounds that deliver oxygen to gasoline in various concentrations. As part of the required reformulation process, oxygenates must be added to gasoline to make up 2 percent of the finished product's weight. A minimum of 2.7 percent oxygen is also required to be added to gasoline sold in 39 areas of the country to reduce carbon monoxide levels during the winter.[7] In the form of ethanol, oxygenate is also blended with conventional gasoline to make gasohol—a gasoline extender and an octane enhancer.

Biofuels are alcohols, such as ethanol or other chemicals, derived from biomass or living matter. Current research is focused on developing biofuels from the starch in corn kernels or from the fibrous cellulosic materials in the rest of the corn plant; it also focuses on cellulosic plants, such as fast-growing trees or grasses, and waste products, such as agricultural and forestry residues and municipal and industrial wastes. A glossary of terms appears at the end of this report.

Cost-Effectiveness Studies Vary in Approach and Results

The following sections summarize the results of studies on the cost-effectiveness of RFG compared to other control options and the estimates for the price of RFG used in the various studies that we reviewed compared with the actual prices experienced.

[5]Volatile organic compounds and nitrogen oxide emissions are two of the more prevalent pollutants that are emitted by motor vehicles and are precursors to ozone pollution.

[6]Initially, the states designated about 40 such areas; however, the states have since petitioned EPA to withdraw 16 of these areas. As discussed later, the Energy Information Administration's long-range projections call for RFG to make up about 35 percent of all gasoline sold in the United States.

[7]According to EPA, the use of oxygenates in its oxygenated fuels program has been steadily decreasing as areas reach attainment for carbon monoxide and, therefore, no longer need to continue in the program.

Cost-Effectiveness Studies

Studies done by EPA, the American Petroleum Institute, Radian Corporation, and Sierra Research, Inc., in conjunction with Charles River Associates, suggest that RFG may be cost-effective when compared with some pollution control measures but less cost-effective than other measures. However, significant differences in the studies' objectives, methodologies, time frames covered, costs considered, types and extent of pollutants considered, and other factors produced widely varying estimates of costs per ton of pollutant removed, a common cost-effectiveness measure. Also, each of the studies evaluated somewhat different control measures and made different assumptions about the extent of the pollution and control measures already in use. These differences make comparisons of results between the studies very difficult. (App. II identifies the four studies that we reviewed and contains tables showing the cost-effectiveness estimates that were made by the various organizations.)

For example, EPA estimates that removing volatile organic compounds using available control measures would cost from about $600 to $6,000 per ton of compounds removed. Specifically, EPA estimates that it would cost about $600 per ton for phase II of the RFG program;[8] $1,300 per ton for enhanced automobile inspection and maintenance programs;[9] $2,000 per ton for on-board diagnostic requirements for automobiles; $5,400 per ton for the basic automobile emission inspection and maintenance program; $5,550 per ton for phase I of the RFG program;[10] and $6,000 per ton for Tier I requirements, which is an EPA emission standard for light-duty vehicles. Officials in EPA's Office of Mobile Sources consider these cost-effectiveness estimates to be inexact, but they consider the estimates to be the best figures that they could develop with the data available to them at that time.

Some regions of the country that are not required to use RFG, but which still need to lower ozone levels, are considering whether to require RFG or

[8]EPA's RFG phase II estimate reflects an incremental cost over the cost of implementing phase I of the RFG program.

[9]When cost-effectiveness estimates are expressed as a range, we used the mid-range for ranking purposes.

[10]According to EPA's regulatory impact analysis and discussions with EPA officials, this amount reflects the total cost of phase I of the RFG program. The amount includes the costs of adding oxygen, reducing benzene, and lowering vapor pressure. The majority of the reductions in volatile organic compounds are attained by lowering vapor pressure, which, according to EPA, costs between $261 and $270 per ton.

gasoline with low vapor pressure.[11] Generally, in the studies that we reviewed, low vapor pressure gasoline was not included as an alternative control measure, but according to refining industry officials, it has the potential to reduce volatile organic compounds (VOC) at a lower cost than RFG. In a February 17, 1994, memorandum to an official in one area considering this option, EPA stated that RFG offers a number of benefits, besides VOC reductions that are due in part to the low vapor pressure of RFG, that low vapor pressure gasoline does not, including the reduction of air toxics and nitrogen oxides (when RFG phase II becomes effective) as well as federal enforcement of the RFG program. EPA also stated that the lower cost of reduced volatility gasoline may be offset in whole or in part by lower competition in the reduced volatility gasoline market.

Projected Versus Actual RFG Prices

We obtained the estimates used for the price of RFG from the four cost-effectiveness studies that we reviewed along with other organizations' price estimates. The estimates varied but were all close to the range of the actual prices experienced during the first 14 months of the RFG program, which began in January 1995. The estimates varied from a low of 3.3 cents to 4.0 cents per gallon more for phase I RFG than the price of conventional gasoline (cited by DOE's Office of Energy Efficiency and Alternative Fuels Policy) to a high of 8.1 cents to 13.7 cents more per gallon (cited by the American Petroleum Institute). EPA estimated that the price of RFG would be from 3.0 cents to 4.9 cents per gallon more than the price of conventional gasoline for phase I of the program.[12]

DOE's Energy Information Administration (EIA) has monitored prices for both conventional gasoline and RFG since the program began in January 1995. In the early weeks of the program, retail prices for RFG were as much as 12 cents a gallon more than those for conventional gasoline. However, March 1996 data indicate that the average gap between RFG and conventional prices had narrowed to about 5 cents per gallon. Furthermore, according to EIA, the price difference may now be closer to 3 cents. (See app. III for additional information on the estimated RFG prices compared with the actual prices experienced.)

[11]Vapor pressure is a measure of gasoline volatility that is expressed as pounds per square inch, with higher pressures resulting in higher volatility and more VOC emissions from evaporation.

[12]EPA's estimates are for the increased cost of producing RFG and would not necessarily reflect the pump price.

Oxygenates Will Displace Some Petroleum

EIA's Annual Energy Outlook for 1996 and supporting documents contain the most current and comprehensive estimate we could find of the potential for using oxygenates to displace the petroleum used to produce gasoline.[13] EIA data indicate that for all uses of oxygenates in gasoline, including the RFG program, about 384,000 barrels per day of oxygenates will be blended with gasoline in the year 2000 and about 394,000 barrels per day in 2010. These projections compare with about 309,000 barrels per day of oxygenates that EIA reports were used in 1995. Adjusting for the lower energy density of oxygenates,[14] the projected level of oxygenate use will potentially displace about 305,000 barrels per day of petroleum used to produce gasoline in 2000 and about 311,000 barrels per day in 2010. (See app. IV for additional information on EIA's projections, along with the energy densities and volume blending ratios of the various oxygenates.)

It is important to note that the above petroleum displacement estimates do not account for differing amounts of petroleum that may be used in the production process for ethanol and the other types of oxygenates. The extent to which petroleum will be used to produce oxygenates depends on several variables and, therefore, is difficult to predict. The greater the amount of petroleum that is used to produce oxygenates, the less petroleum will be displaced. As such, our estimates are likely to be somewhat higher than the displacement that will be actually experienced.

Furthermore, the displacement estimates do not include any possible increases or decreases in refinery outputs made possible by using oxygenates in the refining process. The use of oxygenates could allow some refineries to operate their reformers at lower temperatures, thus increasing the amount of gasoline produced.[15] Doing so, however, may result in reductions in the other petroleum-based products produced, making the total petroleum displacement potential difficult to assess. According to DOE, EIA, and petroleum industry officials, any increase in the finished products related to lower reformer operating temperatures would vary on the basis of the different refinery configurations but, in total, would likely be relatively small. One EIA analysis concludes that, not counting the volume displacement discussed above, the amount of petroleum used in the refining process may actually increase when using oxygenates, but that the increase is not statistically significant.

[13]Annual Energy Outlook 1996 With Projections to 2015, DOE/EIA-0383 (96) (Jan. 1996).

[14]Gasoline-blended fuels that contain oxygenates with a lower energy density than gasoline require a greater volume to achieve the same driving range.

[15]Reforming is one refining process in which crude oil is converted into gasoline and other products.

The 1992 Energy Policy Act requires the Secretary of Energy to determine the technical and economic feasibility of replacing 10 percent of projected motor fuel consumption with nonpetroleum alternative fuels by the year 2000 and 30 percent by 2010. Using the EIA's projected oxygenate use discussed earlier and adjusting for energy density differences, oxygenates would displace about 3.7 percent of the 8.21 million barrels per day of the projected gasoline consumption in 2000 and about 3.6 percent of the 8.64 million barrels per day by 2010. In terms of meeting the act's 10-percent and 30-percent petroleum replacement goals, this amount of displacement will account for about 37 percent of the motor fuel replacement goal for the year 2000 and about 12 percent of the 2010 goal.[16]

Your office also asked us to estimate the level of petroleum displacement if all gasoline sold was reformulated. EIA's projections assume that about 35 percent of all gasoline will be reformulated and another 5 percent will contain some level of oxygenates for other purposes.[17] Assuming the same percentage share for the different types of oxygenates, and other assumptions that EIA used in projecting future oxygenate consumption, we estimate that about 762,000 barrels per day of petroleum would be displaced in the year 2000 and 777,000 barrels per day in 2010, if all gasoline were reformulated. This would amount to about 9.3 percent of projected gasoline consumption in the year 2000 and about 9 percent in 2010. We did not assess the added costs or other implications of reformulating all gasoline.

Successful Research Could Lead to Increased Use of Biofuels

The transportation sector is currently about 97 percent dependent on petroleum-based fuels such as gasoline. According to DOE, this dependence contributes to our vulnerability to oil supply disruptions and related price shocks. DOE and USDA have a number of research projects under way to develop biofuels technologies as alternative transportation fuels. Most of the projects focus on reducing the costs of raw material feedstocks and of transforming the feedstocks into ethanol. Progress has been made in reducing the cost of ethanol, and additional cost reductions are projected in the future. If such reductions are achieved, DOE and USDA expect increased demand for biofuels.

[16]DOE's Policy Office has prepared a draft report that contains similar estimates of oxygenates use and the extent to which oxygenates will contribute to meeting the petroleum displacement goals.

[17]EIA's 40-percent assumption is based on all forms of oxygenate use including RFG, oxygenated gasoline used during the winter months, gasohol, and oxygenate used in conventional gasoline as an octane booster.

Ongoing Federal Biofuels Research

The primary focus of DOE's biofuels program is to produce ethanol from low-cost, high-yield cellulosic feedstocks. These are dedicated energy crops, such as trees that can be grown in short-rotation time periods (3 to 10 years), grasses that can grow on marginal croplands, agricultural residues, and waste products. To a lesser extent, DOE is also conducting research into biofuels technologies to produce biodiesel.[18] The feedstock production research is conducted at DOE's Oak Ridge National Laboratory in Tennessee, where crops grown specifically for energy purposes are studied. Biofuels produced from waste products, such as municipal and industrial wastes, could potentially supply a small portion of transportation fuels in the near future.

DOE's National Renewable Energy Laboratory in Colorado conducts research on converting biomass feedstocks to competitively priced transportation fuels. Research activities include (1) pretreating biomass to facilitate its conversion to fermentable sugars, (2) improving enzyme technologies to convert cellulosic biomass into fermentable sugars, and (3) developing processes to rapidly ferment sugars from biomass materials to ethanol. According to the Director of DOE's Biofuels System Division, the total DOE funding for the transportation biofuels program was about $26 million for fiscal year 1995. (App. V provides more detailed information on DOE's and USDA's biofuels research efforts and describes the process of converting corn and biomass to ethanol.)

The vast majority of USDA's biofuels research program is focused on developing corn starch as a feedstock for ethanol and, to a lesser extent, research to produce biodiesel from farm crops. A small component of USDA's ethanol program is devoted to research on producing ethanol from cellulosic biomass, such as agricultural residues and the remaining portions of the corn plant, such as the cob, hull, stalks, and leaves. USDA's research on conversion technologies focuses on enzyme research to convert feedstocks to fermentable sugars, fermentation improvements to increase ethanol yields, and other processes to minimize the cost of producing ethanol. According to the Director of USDA's Office of Energy and New Uses, the total USDA biofuels research and development funding for fiscal year 1995 was about $10 million.

Cost-Reduction Goals

According to DOE's estimates, advances in research and development have reduced the estimated cost of producing ethanol from biomass energy

[18]Biodiesel is a biofuel made from animal- and vegetable-derived oils that can be used as a substitute or additive to diesel fuel. According to EPA, the use of biodiesel may increase some types of emissions but reduce others.

crops in newly constructed plants from $5.32 per gallon in 1980 to the present estimate of $1.40 per gallon, measured in 1995 dollars, a reduction in real terms of about 74 percent. According to DOE, private companies, using proprietary technologies coupled with zero- or low-cost feedstocks and taking advantage of existing facilities to reduce capital costs, believe they can produce ethanol for 60 to 80 cents per gallon in certain applications. Based on further research in developing lower-cost feedstocks and in improving the process of converting biomass to ethanol, DOE's goal is to produce ethanol at a cost of $0.67 per gallon by 2010, in current dollars. Oak Ridge National Laboratory researchers cautioned us, however, that reaching cost-reduction goals can depend on how much ethanol will need to be produced. For example, DOE has the objective of deploying technologies, by 2010, that could contribute to a national annual production capacity of 518 million barrels of petroleum-equivalent fuels in subsequent years. If that much ethanol were actually in market demand, it would require about 30 million to 50 million acres of land, depending on crop yields and conversion efficiency. As croplands are increasingly used to produce biomass, land costs could increase due to greater competition for land resources. Increasing land costs and other factors, such as regional biomass crop yield differences, could drive the cost higher than $0.67 per gallon.

According to a 1993 USDA analysis and USDA officials, improvements in enzyme and production technologies have reduced the cost of producing a gallon of corn-based ethanol from about $2.50 in 1980, to less than $1.34 in 1992, measured in 1995 dollars, a reduction of about 46 percent in real terms. USDA officials told us that they could not estimate the current cost of producing ethanol because of fluctuations in the price of corn. The officials told us, however, that corn prices are substantially higher today than in 1992. USDA has not developed any cost-reduction goals for corn-based ethanol production.

Potential Demand for Biofuels

According to DOE, the two largest potential markets for biomass-derived fuels are ethanol used as an oxygenate in gasoline or as a fuel itself. While the potential oxygenate market discussed above is limited to blending relatively small percentages of ethanol with gasoline, ethanol used alone as an alternative motor fuel has the potential to replace much larger amounts of gasoline.[19]

[19]Ethanol used as an alternative motor fuel is generally E85 or E100. E85 is a mixture of 85 percent ethanol and 15 percent gasoline. E100 is all ethanol.

The National Renewable Energy Laboratory estimates that by 2020 the demand for biomass ethanol could exceed 14 billion gallons per year. This amount consists of a demand of 3 billion gallons per year to be used as an oxygenate and 11 billion gallons per year for ethanol to be used as a replacement fuel for gasoline.[20] This long-term projection is based on achieving a market price for ethanol that is predicted to be competitive with the price of gasoline.[21]

DOE's Energy Efficiency and Renewable Energy Program Office also provided us with an estimate of transportation biofuels use, which shows an increasing use of biofuels from 126 million gallons in the year 2000 to 4.6 billion gallons and 10.8 billion gallons, respectively, in 2010 and 2020. While these estimates differ somewhat from the estimates provided by DOE's laboratory, the differences reflect the uncertainties involved in making such projections. Both sets of estimates, however, predict growing use of biofuels, particularly beyond 2010 when such fuels are expected to be used as a replacement for gasoline.

USDA has not projected ethanol demand on the basis of reductions in ethanol production costs. However, USDA's 1993 analysis showed that further expansion of ethanol from corn is limited because of the high price of corn and the fact that corn has many alternative uses. According to the analysis, these restrictions do not apply to biomass feedstocks that could supplement corn as an inexpensive ethanol feedstock. According to DOE and USDA officials, many technical and economic barriers must be overcome to achieve a significant increase in the demand for biofuels. These barriers include limited funding for the successful development and commercialization of the biomass technologies discussed above, as well as achieving the cost-reduction goals mentioned earlier.

Agency Comments

We provided copies of a draft of this report to DOE, EPA, and USDA for their review and comment. DOE suggested several changes to clarify information in the report. We incorporated DOE's comments where appropriate.

[20]The 3 billion gallons equate to about 131,100 barrels per day, adjusted for the energy content of ethanol. This figure would be somewhat higher if ethanol was used to produce ethyl tertiary butyl ether. The 11 billion gallons equate to about 480,800 barrels per day.

[21]EIA projects that gasoline consumption would be 8.56 million barrels per day in 2015. Assuming that gasoline consumption remains constant, we estimate that DOE's projected level of ethanol use would represent about 7.1 percent of gasoline consumption in 2020. This estimate includes an adjustment made for ethanol's lower energy content.

Both EPA and USDA expressed concerns with our discussion in appendix III on the average price of RFG over the life of the RFG program compared to conventional gasoline. The agencies believe that the average price is misleading because it would reflect the very high price of RFG experienced at the start of the program. The officials also believe that the more recent price difference of about 3 cents to 5 cents per gallon is more accurate. We concur with these comments and deleted the reference to the average RFG price difference.

EPA said that EIA's projections for the future displacement of petroleum by the use of oxygenates seem higher than what it would expect. According to EPA, while it is encouraging states to use RFG where its use is now optional, it expects that the amount of petroleum displaced by the use of oxygenates in future years will be modest. The reasons cited by EPA were that the oxygenate requirements of the RFG program do not change over time, the number of areas participating in the RFG program has remained fairly stable, and the number of areas participating in the wintertime oxygenated fuels program have been decreasing as the program succeeds in bring areas into attainment for carbon monoxide.

EIA projections show a 24.3- and 27.5-percent increase in oxygenate use in 2000 and 2010, respectively, over 1995 levels. According to EIA, these increases are based on several factors, including California's recent statewide adoption of more severely reformulated gasoline requirements and projected increases in gasoline consumption, including RFG. In addition, the projections took into consideration the declining use of oxygenates in the wintertime oxygenated fuels program and do not include the expanded use of ethanol as an alternative fuel.[22] Finally, EIA assumed a constant market share of about 35 percent for RFG throughout the forecast period. The above factors and assumptions used by EIA seem reasonable to us, but we agree that to the extent the projected increases in oxygenate use do not take place, the amount of petroleum displaced would be less.

USDA said that from its perspective, our report does not sufficiently analyze the competing information contained in the RFG studies summarized in our report or critique the cost-effectiveness estimates that were examined.

[22]According to an EIA official responsible for forecasts in this area, some additional areas that dropped out of the oxygenated fuels program in the fall of 1995 would not have been taken into account in EIA's estimate of oxygenate use for the 1996 Annual Energy Outlook. However, the EIA official believes that the effect on the projected use of oxygenates would not be significant.

As stated earlier, our objective in this area was to summarize the results of studies on the cost-effectiveness of using reformulated gasoline compared to other measures to control automotive emissions. We state in the report that significant differences in the studies' objectives, methodologies, time frames covered, costs considered, types and extent of pollutants considered, and other factors produced widely varying estimates of cost-effectiveness. A critique of the studies' results or comparing the results on an equal basis may be useful but would require redoing the studies, controlling for each of the factors cited above. Such an analysis was beyond the scope of our review.

Appendices VI, VII, and VIII contain DOE's, EPA's, and USDA's comments, respectively, along with our responses where appropriate. App. IX describes the objectives, scope, and methodology.

We performed our work from July 1995 through April 1996 in accordance with generally accepted government auditing standards.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 14 days from the date of this report. At that time, we will send copies of this report to interested congressional committees, the Secretary of Energy, the Secretary of Agriculture, and the Administrator of EPA. We will also make copies available to others upon request.

Please call me at (202) 512-3841 if you have any questions. Major contributors to this report are listed in appendix X.

Sincerely yours,

Victor S. Rezendes
Director, Energy, Resources,
and Science Issues

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Abbreviations

API	American Petroleum Institute
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ETBE	ethyl tertiary butyl ether
GAO	General Accounting Office
MTBE	methyl tertiary butyl ether
NOx	nitrogen oxide
psi	pounds per square inch
RFG	reformulated gasoline
TAME	tertiary amyl methyl ether
USDA	U.S. Department of Agriculture
VOC	volatile organic compound

Greenhouse Gas Emission Characteristics of Reformulated Gasoline

This appendix summarizes the results of a 1995 study performed by the Department of Energy's (DOE) Argonne National Laboratory, which evaluated, among other things, the greenhouse gas emission characteristics of reformulated gasoline (RFG).[1] This is the most current and comprehensive study that we could find on this issue.

The study indicates that RFG's potential to reduce greenhouse gases is small. According to the study, the effects of using RFG on greenhouse gas emissions varies according to (1) the specific oxygenate that is added to conventional gasoline and (2) the time of year that RFG is used. According to one of the study's authors, the time of year is a factor because of the volatile organic compound (VOC) reduction requirements for high ozone season (summer) RFG. Table I.1 shows the comparative carbon dioxide equivalent emissions, a common measure of greenhouse gases, of RFG made with ethyl tertiary butyl ether (ETBE), an ether made from ethanol;[2] methyl tertiary butyl ether (MTBE), an ether made from methanol; conventional gasoline; and RFG made with ETBE, derived from ethanol produced with new or additional rather than existing agricultural sources.

Table I.1: Comparisons of Emissions of Greenhouse Gases for Reformulated and Conventional Gasoline

	Carbon Dioxide Equivalent Emissions (grams)	
Fuel	**Winter**	**Summer**
Reformulated gasoline[a] (existing)[b]	11,422	11,794
Conventional gasoline	11,545	11,821
Reformulated gasoline w/MTBE	11,389	11,844
Reformulated gasoline[a] (new)[c]	11,568	11,926

[a]ETBE is used in RFG in the summer and ethanol is used in the winter.

[b]Diverted from existing ethanol markets.

[c]ETBE is derived from ethanol beyond that which is currently being produced.

The table shows that in the summer when ozone problems are most severe, ETBE made with existing sources of ethanol produces the least

[1]Impact of the Renewable Oxygenate Standard for Reformulated Gasoline on Ethanol Demand, Energy Use, and Greenhouse Gas Emissions, ANL/ESD-28, Argonne National Laboratory, (Apr. 1995).

[2]Greenhouse gases can be generically measured in carbon dioxide equivalents. This term is a measure representing the weighted impact of the emissions of all greenhouse gases, including carbon dioxide, water vapor, methane, nitrous oxide, and chlorofluorocarbons.

amount of greenhouse gases;[3] while ETBE from new sources of ethanol emits the highest amount of greenhouse gases. Emissions of greenhouse gases from conventional gasoline are the second lowest, followed by emissions from RFG made with MTBE. In all cases, however, as discussed above, the difference in greenhouse gas emissions between RFG and conventional gasoline is small.

Nearly all ethanol is currently made with corn. According to the Department of Agriculture, current research on using biomass feedstocks to produce ethanol, combined with improved production processes, may lead to greater reductions of greenhouse gases for RFG made with ethanol. However, a DOE official noted that while ethanol made with biomass can significantly reduce the amount of greenhouse gas emissions compared with corn-based ethanol, all oxygenates comprise only a small part of the RFG mixture. Hence, unless the use of RFG becomes more widespread, and specifically RFG made with ethanol derived from biomass, the potential for large greenhouse gas reductions appears limited.

[3]One of the study's authors explained that existing ethanol is ethanol that is derived from existing markets where the ethanol is then replaced by conventional gasoline.

Summary of Reformulated Gasoline Cost-Effectiveness Comparisons by Various Organizations

The Environmental Protection Agency (EPA), the American Petroleum Institute (API), Radian Corporation, and Sierra Research, Inc., in conjunction with Charles River Associates, conducted studies of the cost-effectiveness of RFG compared to other automotive emission control measures. A list of the studies follows.

"Final Regulatory Impact Analysis for Reformulated Gasoline," EPA (Dec. 1993).

"The Cost Effectiveness of VOC and NOx Emission Control Measures," Publication No. 326, API (Sept. 1994).

"Emission Reductions and Costs of Mobile Source Controls," DCN92-221-054-01, Radian Corporation (Dec. 1992).

"The Cost-Effectiveness of Further Regulating Mobile Source Emissions," SR94-02-04, Sierra Research, Inc., and Charles River Associates (Feb. 1994).

Tables II.1-II.5 and accompanying narrative contain the results of the cost-effectiveness analyses made by the various organizations that we reviewed. The costs indicated are expressed in dollars per ton of volatile organic compounds (VOC), nitrogen oxide (NOx), or air toxics removed. Significant differences in the analyses' objectives, methodologies, time frames, costs considered, and other factors produced varying estimates of costs per ton of pollutant removed. Also, each of the analyses evaluated somewhat different control measures, making comparisons among the studies very difficult.

An API analyst reported on various estimates of the cost-effectiveness of emission control strategies and found several problems that make comparison among the studies' results very difficult.[1] The analyst found that cost-effectiveness is dependent on several factors, including the baseline emission level, whether cost-effectiveness is calculated on a marginal or total cost-effectiveness basis, the assignment of control costs for different emission reductions, the extent of emission reductions in attainment areas, and the seasonality of ozone pollution, which would vary from locality to locality.

[1] Improving Cost-Effectiveness Estimation: A Reassessment of Control Options to Reduce Ozone Precursor Emissions, Research Study #075, American Petroleum Institute, (Aug. 1994).

Environmental Protection Agency

Table II.1 contains cost comparisons, which are drawn from EPA's 1993 Regulatory Impact Analysis for the RFG program. Some of the costs reflected in the table are the total costs of implementing some control measures and others are the incremental costs—the additional costs—incurred to implement control measures with more stringent requirements that are added to earlier measures. For example, the costs reflected for phase I of the federal RFG program are the total costs of that measure. Whereas, phase II of the RFG program reflects the incremental cost of implementing more stringent requirements in addition to phase I of the program. The glossary at the end of this report defines the control measures identified in this table and subsequent tables, as well as other terms that are contained in this report.

Table II.1: Comparison of EPA's Cost Estimates for Several Mobile Source Control Measures for Reducing VOC Emissions

Control measures	Cost per ton of VOC reduction
Reformulated gasoline—phase II	$600[a]
Enhanced automobile emission inspection and maintenance program	$900 to $1,700
On-board automobile emissions diagnostic equipment	$2,000
Basic automobile emission inspection program	$5,400
Reformulated gasoline—phase I	$5,200 to $5,900[b]
Stricter emission standards for light-duty vehicles (tier I)	$6,000

[a]Meeting RFG phase II requirements by controlling the vapor pressure and sulfur in gasoline to 6.7 pounds per square inch (psi) and 250 parts per million, respectively, could yield a reduction from baseline VOC emissions of about 26 percent at an incremental cost-effectiveness of about $3,700 per ton of VOC reduced. The estimates for RFG phase II represents costs in addition to those in RFG phase I.

[b]According to EPA's regulatory impact analysis and discussions with EPA officials, this amount reflects the total cost of phase I of the RFG program. The amount includes the costs of adding oxygen, reducing benzene, and lowering vapor pressure. The majority of VOC reductions are attained by lowering vapor pressure, which, according to EPA, costs between $261 and $270 per ton.

EPA officials told us that because the Clean Air Act Amendments of 1990 mandated the RFG program, the regulatory impact analysis focused on the cost differences of various RFG formulas and, therefore, contained only limited information comparing RFG with other control measures. Even this focus was constrained somewhat because the legislation specified that oxygen must make up a minimum of 2 percent of the RFG's total weight. EPA also estimated the cost of RFG phase II in removing NO_x at about $3,700 per ton and the cost of removing air toxics at about $40,000 per ton for RFG phase I.

EPA has recognized the limitations of the cost-effectiveness information for RFG and specifically the need for additional information that compares the costs of the RFG program with other control measures. According to an official in EPA's Office of Mobile Sources, the cost figures used in the regulatory impact analysis are the best available from EPA. Furthermore, EPA officials said that comparative data are not readily available for most of the other control measures because the purposes of these programs are not the same as the RFG program, especially with regard to reducing NOx and air toxic emissions. RFG phase I is ranked fifth of the six control measures listed in table II.1.

American Petroleum Institute

Table II.2 summarizes the results of API's analysis of the cost-effectiveness of the RFG program in reducing VOC and NOx emissions in five cities. The analysis was prepared for API by Radian Corporation.

Table II.2: Analysis of API's Cost-Effectiveness Estimates for the Reformulated Gasoline Program for Reducing VOC and NOx Emissions in Five Cities (1993 Dollars)

	Weighted annual costs per ton reduction[a]	
City	**VOC**	**NOx**
Chicago	$3,302	$30,440
Philadelphia	$3,992	$43,843
Houston	$9,357	$36,668
Baltimore	$9,742	$37,904
Washington, D.C.	$10,716	$44,205
Average	**$7,422**	**$38,612**

[a]The study assumed the ozone reduction benefits were obtained for only 6 months of the year; therefore, annual costs for reducing VOCs were reduced by 50 percent.

The study found that there were major differences among the cost-effectiveness of RFG among the five cities. In some cities, RFG is up to three times more cost-effective than in other cities. The data take into consideration the vapor pressure of gasoline sold in these cities and other factors, such as the length of the ozone season that varies by city. The study indicates that a primary reason for the RFG cost-effectiveness differences was the vapor pressure of the gasoline used in those cities. The data show that the lower costs for VOC reductions are in the cities that use gasoline with higher vapor pressures.[2] Table II.2 contains values for the years 1995 through 2004 and, therefore, includes cost figures for NOx control that is part of the phase II RFG program.

[2]The vapor pressure for Chicago and Philadelphia was 8.0 psi and for Baltimore, Houston, and Washington, D.C., the vapor pressure was 7.1 psi.

Table II.3 summarizes comparisons of mid-range cost estimates by API for RFG in the five cities reviewed with other control measures for VOC and NOx. These figures also reflect estimates for the years 1995 through 2004. The table shows that RFG is ranked second out of the eight control measures studied for VOC.

Table II.3: Comparison of API's Cost-Effectiveness Estimates of Mobile Source Control Measures for Reducing VOC and NOx Emissions (1993 Dollars)

	Cost per ton of reduction[a]	
Control measures	**VOC**	**NOx**
Refueling vapor recovery equipment (stage II)	$2,802	[b]
Reformulated gasoline (phases I and II)	$7,422	$38,612
Enhanced automobile emission inspection and maintenance program	$13,621	$17,030
Vehicle scrappage program	$14,153	[b]
Expanded automobile emission inspection and maintenance program	$14,243	[b]
Use of natural gas-fueled vehicles	$25,338	[b]
California's stricter reformulated gasoline	$55,164	$18,190
California's low emission vehicle requirements	$297,703	$139,880

[a]The cost per ton is an annual average for the five cities that API included in its study, except for the RFG program whose annual costs were reduced by 50 percent because the reduced ozone benefits are only realized during 6 months of the year.

[b]Data not available.

Radian Corporation

Table II.4 summarizes Radian Corporation's study of the emission reductions, costs, and cost-effectiveness of different mobile source control strategies. The study was prepared for the Virginia Petroleum Council, for the Virginia State Legislature's use in determining which air pollution control measures to adopt in Northern Virginia. The table shows that RFG is ranked seventh out of the eight control measures.

Table II.4: Radian Corporation Comparison of Emission Reductions and Costs of Mobile Source Controls (1993 Dollars)

Control measures	Cost per ton of reduction[a]
Refueling vapor recovery equipment (stage II)	$2,820
Enhanced automobile emission inspection and maintenance program	$5,940
Maximum automobile emission inspection and maintenance program (with tier II)[b]	$7,440
Maximum automobile emission inspection and maintenance program (with tier I)[c]	$7,500
Clean fleet vehicle program	$11,856
Vehicle scrappage program	$12,420
Reformulated gasoline (phases I and II)	$14,700
Low emissions vehicle program	$18,500 to $37,700

[a]The amount of pollutant removed was calculated by adding the total of VOC reductions to one-half of the NOx reductions. The cost reductions are for the year 1999. Radian also calculated the costs for the year 2015. The ranking of RFG compared to the other control measures (based on cost per ton emission reduction) did not change in 2015.

[b]Assumes that tier II emission standards for light-duty vehicles will be met.

[c]Assumes that tier I emission standards for light-duty vehicles will be met.

Sierra Research, Inc., and Charles River Associates

Sierra Research, Inc., and Charles River Associates' study estimated the cost-effectiveness of mobile source emissions control measures required by the Clean Air Act Amendments of 1990 and the California Air Resources Board regulations. The study was prepared for the American Automobile Manufacturers Association. Table II.5 summarizes the results of the key control measures identified in the study. RFG is ranked fourth out of the 14 mobile source control measures.

Table II.5: Sierra Research, Inc., and Charles River Associates Comparison of the Cost Effectiveness of Mobile Source Control Measures

Control measures	Cost per ton of reduction[a]
Reid vapor pressure control	$1,100
Enhanced automobile emission inspection and maintenance program	$1,700
Refueling vapor recovery equipment (stage II)	$3,300
Reformulated gasoline	$4,600
California phase II reformulated gasoline	$6,100
New evaporative standards and test procedures to control vehicle emissions	$6,300
Stricter emissions standards for light-duty vehicles (tier I)	$12,100
Vehicle scrappage program	$13,900
Transitional low emissions vehicle program	$26,200
Low emissions vehicle program	$40,600
Stricter emissions standards for light-duty vehicles (tier II)	$46,400
On-board automobile emissions diagnostic equipment	$58,500
Ultra low emissions vehicle program	$72,800
Zero emissions vehicle program	$173,600

[a]The cost of emission reductions includes VOC, NOx, and one-seventh of carbon monoxide emissions. The analysis reflects nationwide emission reductions occurring in nonattainment areas during the season when violations of the air quality standards occur. The methodology used would result in higher costs per ton of emissions reduction since emission reductions occurring at other times and locations were not counted.

Comparison of Estimated Reformulated Gasoline Prices With Actual Prices

This appendix compares the price estimates used for RFG in the four cost-effectiveness studies that we reviewed, along with the price estimates of other organizations, with the actual RFG prices reported by DOE's Energy Information Administration (EIA).

Table III.1: Comparison of Estimated Price Increases for RFG by Various Organizations

Cents per gallon

Organizations	Phase I	Phase II
DOE Office of Policy	3.3-4.0	6.9-9.3
EPA[a]	3.0-4.9	3.2-5.9
EIA	4.0-6.0	[b]
Radian Corporation[c]	7.0	11.0
Sierra Research, Inc., and Charles River Associates	7.3	10.9
National Petroleum Council	8.0	9.0-11.1
New York State Energy Research and Development Authority	9.1[d]	10.5
API[e]	8.1-13.7	9.8-17.6

[a]EPA's estimates are for the increased cost of producing RFG; not necessarily the increased price. The estimates include an adjustment of about 2 cents per gallon for the loss in fuel economy associated primarily with the oxygen requirement.

[b]Data were unavailable for phase II of the RFG program.

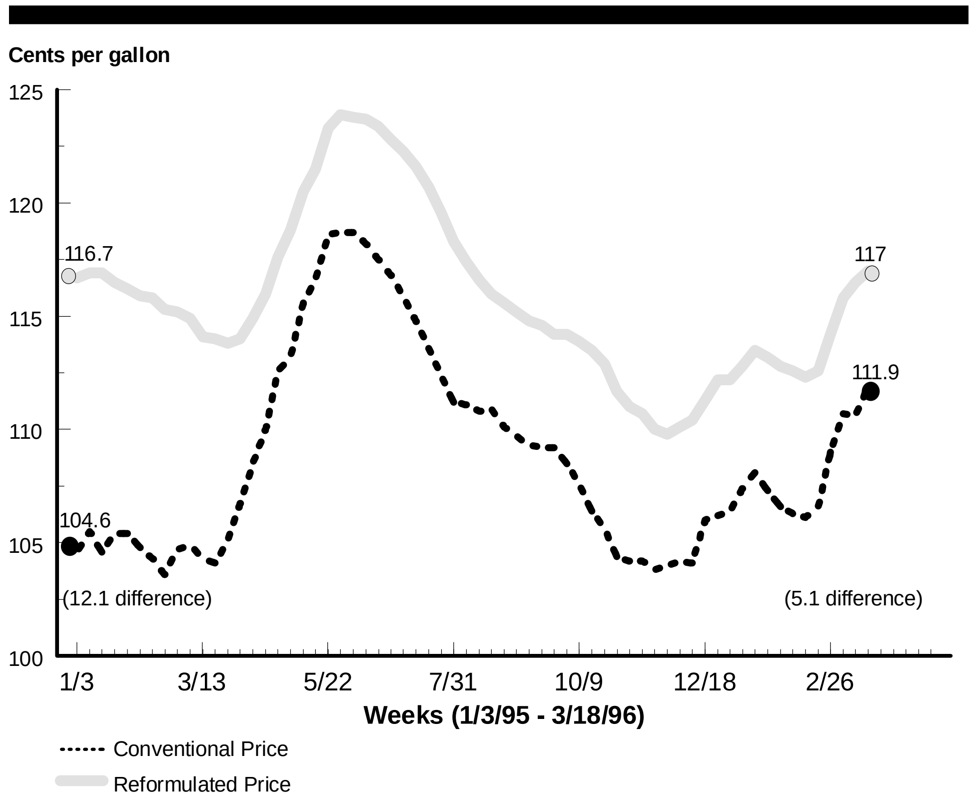
[c]In addition, a 3-cents per gallon fuel economy penalty was assumed.

[d]Price is for the 1998-1999 portion of phase I of the RFG program.

[e]API included several cost categories such as refining, oxygenates, fuel economy penalty, stationary source controls, logistics, and retail marketing regulations in its cost-effectiveness study, which made API's costs per gallon higher. When only those cost categories used by EPA are considered, API's estimate is about 8 cents to about 10 cents per gallon more.

EIA has monitored prices of both conventional gasoline and RFG since the RFG program began. Figure III.1 shows EIA data on actual retail prices from the beginning of the RFG program in January 1995 through the week of March 18, 1996.

Figure III.1: Comparison of the Average Retail Prices of Conventional and Reformulated Gasoline



Source: GAO illustration based on data provided by EIA.

The EIA data show that in the early weeks of the program, average retail prices for RFG were as much as 12 cents a gallon more than those for conventional gasoline. However, more recent data indicate that the average gap between RFG and conventional gasoline prices had narrowed to about 5 cents per gallon. Furthermore, according to EIA, the price difference may now be closer to 3 cents.

Potential Petroleum Displacement From Using Oxygenated Fuels

This appendix discusses the potential petroleum displacement from using oxygenated fuels, identifies some of EIA's assumptions used in its Annual Energy Outlook for 1996 to forecast gasoline and oxygenate consumption, and provides information on the volume and energy density of oxygenates blended with gasoline.

Table IV.1: Projected Use and Potential Petroleum Displacement From Using Oxygenates in Gasoline in 2000 and 2010

Barrels per day

	2000		2010	
Type of oxygenate	**Projected oxygenate use**	**Potential petroleum displacement[a]**	**Projected oxygenate use**	**Potential petroleum displacement[a]**
Ethanol[b]	70,000	46,900	90,000	60,300
ETBE	0	0	28,000	23,800
MTBE	310,000	254,200	270,000	221,400
TAME[c]	4,000	3,520	6,000	5,280
Total	**384,000**	**304,620**	**394,000**	**310,780**

[a]The projected oxygenate use was adjusted for the lower energy density of the oxygenate to arrive at its potential petroleum displacement. No adjustment was made for the petroleum content used to produce the oxygenate. For example, MTBE is produced from methanol (an alcohol made primarily from natural gas) and isobutylene, which may be produced from petroleum within a refinery or derived from natural gas outside a refinery. The extent to which petroleum will be used to produce oxygenates depends on several variables and, therefore, is difficult to predict. The greater the amount of petroleum that is used to produce oxygenates, the less petroleum will be displaced. More detailed information on the extent of petroleum used to produce oxygenates can be found in the Argonne National Laboratory April 1995 report referred to in appendix I.

[b]In addition to the 90,000 barrels of ethanol blended with gasoline in 2010, EIA's forecast shows that an additional 70,000 barrels of ethanol will be used in E85, an alternative motor fuel consisting of 85 percent ethanol and 15 percent gasoline.

[c]TAME represents tertiary amyl methyl ether.

Assumptions in EIA's 1996 Annual Energy Outlook

EIA used several assumptions in forecasting gasoline and oxygenate consumption to 2015. Some of the key assumptions are described as follows:

- EIA assumes that the tax exemption of $0.54 per gallon of ethanol will continue past the year 2000 to 2015.[1] The subsidy is in nominal terms.
- EIA models the production and distribution of four different types of gasoline: traditional, oxygenated, reformulated, and reformulated/high oxygen. RFG is assumed to account for about 35 percent of annual gasoline sales throughout the forecast. The total estimated market for all

[1]Ethanol fuels are exempt from 5.4 cents of the total amount of the per gallon tax imposed on gasoline sales (for 90-percent gasoline/10-percent ethanol blends).

oxygenated fuels, including RFG and traditional gasoline that may contain some oxygenates, is about 40 percent throughout the forecast.

- Oxygenated gasoline, which has been required during winter months in many U.S. cities to control carbon monoxide emissions, requires an oxygen content of 2.7 percent by weight.
- Reformulated/high oxygen gasoline, used in overlapping areas that require oxygenated gasoline and RFG, requires 2.7 percent oxygen.
- RFG requires 2.0 percent oxygen by weight. EIA assumes that RFG will be certified in accordance with the EPA models.
- Only ethanol made from corn is currently modeled. About 95 percent of the U.S. production of fuel ethanol is derived from corn.
- The Energy Policy Act of 1992 mandates that government, business, and fuel providers purchase a specified percentage of alternative-fueled vehicles in their fleets. EIA assumed that both business and fuel-provider fleet mandates do not take effect until the year 2000. (Footnote "b" in table IV.1 shows that some ethanol will be used in E85, an alternative motor fuel, in 2010.)

Table IV.2: Volume of Oxygenates Blended With Gasoline to Meet Various Oxygen Requirements

Percent of oxygen requirement by weight[a]	Gasoline blending component			
	Ethanol	ETBE	MTBE	TAME
2.0	5.7	12.0	11.0	12.4
2.7	7.7	17.2	15.0	16.7
3.5	10.0[b]	[b]	[b]	[b]

[a]The Clean Air Act Amendments of 1990 require that RFG be blended at a minimum oxygen weight of 2.0 percent to control ozone levels and that other oxygenated fuels be blended at a minimum of 2.7 percent to control carbon monoxide emissions. EPA regulations allow ethanol to be blended at a 3.5-percent rate.

[b]Prior to March 18, 1996, EPA's RFG fuel regulations did not allow oxygenates to be blended above 2.7 percent oxygen by weight during the summer high ozone season. EPA revised these fuel regulations effective March 18, 1996, allowing higher concentrations of oxygenates under certain circumstances. EPA does not expect significantly higher use of oxygenates as a result of this change.

Table IV.3: Energy Content of Oxygenates Relative to Gasoline

	British thermal unit[a] per gallon[b]	Percent of gasoline
Gasoline	114,000	100
Ethanol	76,100	67
ETBE	96,900	85
MTBE	93,500	82
TAME	100,700	88

[a]British thermal unit is a standard unit for measuring the quantity of heat energy equal to the quantity of heat required to raise the temperature of 1 pound of water by 1 degree Fahrenheit.

[b]Gasoline-blended fuels with a lower energy density than gasoline require a greater volume to achieve the same driving range.

DOE and USDA Biofuel Research Efforts

DOE and the Department of Agriculture (USDA) have several research projects to develop biofuels technologies from renewable resources for the transportation fuel market. This appendix provides additional information on the agencies' efforts. The appendix also shows the processes for converting corn and biomass to ethanol.

DOE's Biofuels Research Efforts

Since the ethanol supply is limited due in part to the high cost of corn feedstocks and the use of corn for other purposes, DOE's biofuels research program is aimed at developing biomass-based transportation fuels from cellulosic feedstocks. Such feedstocks are derived from renewable resources such as grasses, trees, and waste products. DOE is also conducting research to convert these feedstocks to liquid transportation fuels. DOE's program envisions that such fuels have the potential to displace a large percentage of petroleum-based transportation fuels in the future. The following summary outlines the focus of DOE's biofuels research efforts.

To lower the cost of cellulosic feedstocks, the Oak Ridge National Laboratory leads a research and analysis program with many collaborators nationwide to

- identify and develop plants that can be used as high-yield dedicated energy crops on excess cropland;
- develop specialized site management, crop management, harvest and handling techniques to obtain optimum yields from plants with high-yield potential;
- identify crop production techniques that ensure the protection of the environment and natural resources;
- identify locations where high-yields can be achieved on low cost land; and
- obtain cost, risk, and environmental data under operational conditions by collaborating with private industry, USDA, and local organizations to demonstrate crop production systems.

To lower feedstock conversion costs, the National Renewable Energy Laboratory is conducting biofuels research to

- demonstrate a process to convert 1 ton per day of cellulosic waste feedstock to produce 100 gallons of ethanol in cooperation with industrial partners;
- demonstrate a process of using the cellulosic fiber of the corn kernel to improve yields;

- develop and evaluate a new process that combines two main biomass sugar fermentation steps into one, to decrease the production time and increase yields;
- develop new cellulase enzymes that more economically degrade cellulose to sugar;
- determine the potential to produce ethanol from switchgrasses, sugarcane, tropical grasses, trees, paper and sawmill wastes, forestry residues, and rice straw; and
- develop new technologies to produce biodiesel from waste fats and oils.[1]

USDA's Biofuels Research Efforts

The cost of producing ethanol from corn depends on several factors, including the price of corn, the value of co-products, the cost of energy and enzymes, the size of the production plants, and the level of technology in the plant. USDA's efforts have largely focused on improving technologies that would increase the efficiencies of feedstocks (primarily corn), speed up the production process, and raise the yield of ethanol in order to reduce its overall cost. USDA conducts or funds biofuels research on the projects summarized below.

To lower the cost of feedstocks, USDA research is conducted on

- starches, such as corn, wheat, sorghum, and potatoes;
- fruit and vegetable by-products;
- corn cobs, straws, and corn hulls;
- corn stover and grasses;
- potential energy crops such as trees (e.g., evaluate the energy yield from short rotation of different types of woods); and
- agricultural residues.

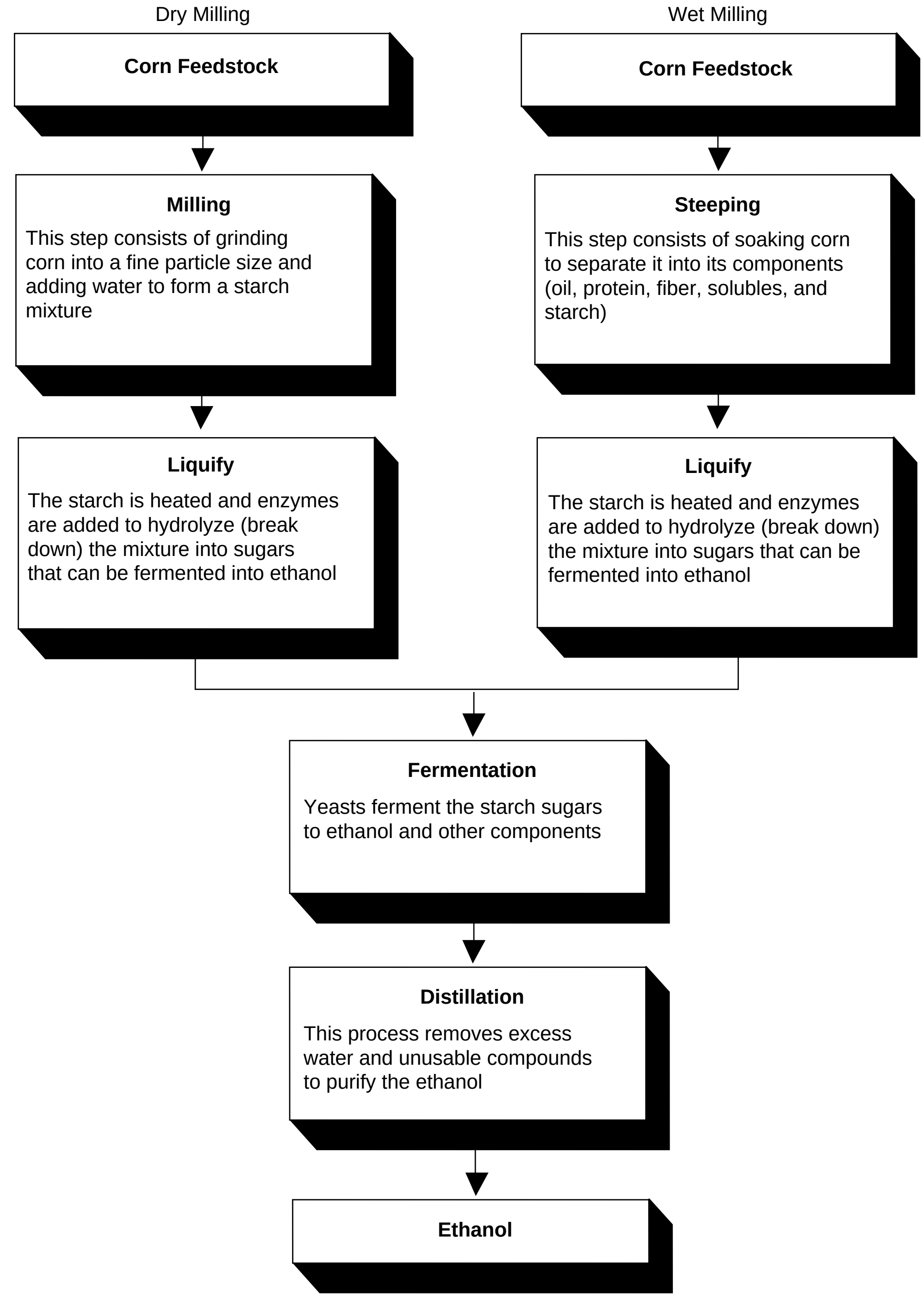
To lower feedstock conversion costs, USDA research is conducted on

- organisms that can produce ethanol from various feedstocks through genetic engineering;
- biomass conversion processes to convert feedstocks to fermentable sugars through more efficient and cost-effective use of enzymes;
- processes to increase the yield of ethanol and other co-products, such as food additives; and
- advanced fermentation technologies to more efficiently and cost effectively produce ethanol.

[1]Biodiesel is a biofuel made from animal and vegetable derived oils that can be used as a substitute or additive to diesel fuel. According to EPA, the use of biodiesel may increase some types of emissions but reduce others.

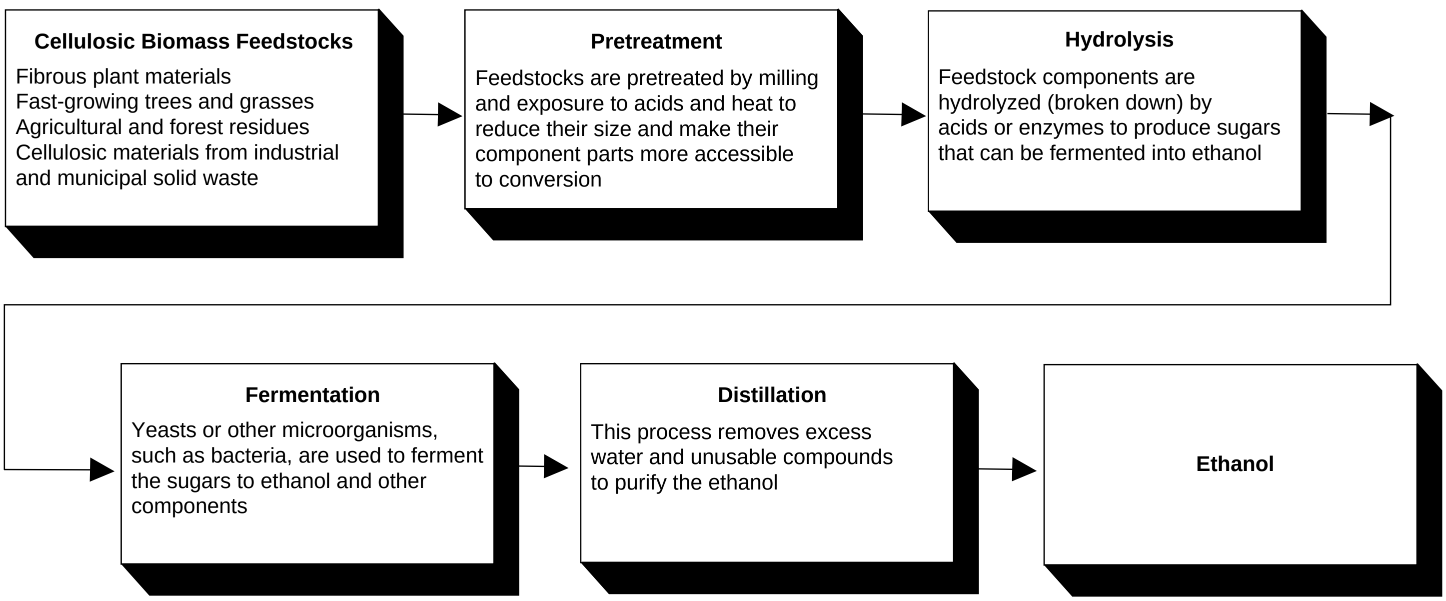
Two primary methods are used to make ethanol from corn: dry milling and wet milling. Dry milling, used for about one-third of ethanol production, is used to produce mainly ethanol, while wet milling generates ethanol and a variety of co-products, such as corn oil, animal feed, and other starch products. Figure V.1 illustrates the process used to convert corn into ethanol.

Figure V.1: Corn-To-Ethanol Conversion Process



DOE's biofuels research focuses on developing biomass-based transportation fuels from cellulosic feedstocks. Figure V.2 illustrates the process used to convert biomass feedstocks into ethanol.

Figure V.2: Biomass-To-Ethanol Conversion Process



Comments From the Department of Energy

Department of Energy
Washington, DC 20585

May 22, 1996

Mr. Victor S. Rezendes
Director, Energy Resources,
and Science Issues
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Rezendes:

The Department of Energy appreciates the opportunity to review and comment on the General Accounting Office draft report GAO/RCED-96-121, "Motor Fuels: Issues related to Reformulated Gasoline, Oxygenated Fuels, and Biofuels."

Minor editorial changes have been provided to the General Accounting Office under separate cover. The Department hopes that our input will be helpful in the preparation of the final report.

Sincerely,

for Christine A. Ervin
Assistant Secretary
Energy Efficiency and Renewable Energy

Printed with soy ink on recycled paper

Comments From the Environmental Protection Agency

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

MAY 17 1996

OFFICE OF
AIR AND RADIATION

Mr. Victor S. Rezendes
Director
Energy, Resources and Science Issues
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Rezendes:

Thank you for giving the Environmental Protection Agency (EPA) the opportunity to review your draft report "Motor Fuels: Issues related to Reformulated Gasoline, Oxygenated Fuels, and Biofuels," (GAO/RCED-96-121, Code 308888). Our complete comments are enclosed for your consideration.

Now on p. 5.

Now on p. 27.

I would like to call your attention to two comments which are of particular concern to us. The first concerns the discussion of the price of reformulated gasoline (RFG) compared to conventional (non-reformulated) gasoline. In both the body of the report (pages 6-7) and in Appendix III, the difference between various estimates of the cost of RFG is discussed and compared with the actual price differential experienced over the life of the program to date. The most recent reports of the price differential, as indicated on page 32 of your report, show that RFG costs 3-5 cents per gallon more than conventional gasoline. This range is very consistent with EPA's original estimates and our understanding of the current market situation. However, on page 7 of your report the emphasis seems to be on the average cost over the life of the program, calculated to be 7 cents per gallon. This higher figure is due largely to the very high prices experienced at the start of the program, which were quickly reduced once the market adjusted and adequate RFG was made available. As time goes on, the average will approach the current trend, minimizing the effects of the initial price spike. We believe that it is misleading to the reader to discuss this average cost, which is influenced by an aberration at the start of the program. As indicated in our comments, we recommend that you delete the discussion of the average price difference and furthermore that the full range of EIA-reported cost differentials (3-5 cents/gal) be discussed on page 7 as it is on page 32.

Our second major comment concerns the use of EIA projections from the Annual Energy Outlook regarding the future displacement of petroleum by the use of oxygenates. Oxygenates may be used for the EPA federal RFG program, the wintertime oxygenated fuels program, or for the expanded use of ethanol as E85 or E100. While the Agency is currently seeking to expand opportunities for areas to "opt-in" to the RFG program and is encouraging states to consider this option, we expect that the increased use of oxygenates due to any increase in participation in the RFG program will be modest. In addition, the use of oxygenates in our very successful wintertime oxygenated fuels program has been steadily decreasing as areas reach attainment for carbon monoxide and no longer need to continue in the program. EIA's conclusions about substantial growth in the use of oxygenates may in part be based on their assumptions about the expanded use of ethanol as E85 and E100. Excluding such assumptions, however, the projections seem to be higher than we would expect. You may want to identify the level of oxygenate use that is required by EPA's programs separate from any incremental increase expected due to assumptions about market expansion as a result of DOE programs or other driving forces.

As you will see, the majority of our remaining comments serve to clarify details of the RFG program or to correct minor errors in the report. Please contact me or Susan Willis of my staff (313/668-4432) with any questions about these comments. Once again, we appreciate the opportunity to comment on this draft and will be happy to work with you and your staff to address our concerns.

Sincerely,

Charles N. Freed
Director
Fuels and Energy Division

Enclosure

cc: Pete Cosier, OAR/OPMO
Steve Tiber, OARM/RMD
Laszlo Bockh, OAR/OMS

EPA comments on draft GAO study, "Motor Fuels: Issues related to Reformulated Gasoline, Oxygenated Fuels, and Biofuels"

See comment 1.

p. 1 (general comment) The reformulated gasoline (RFG) program is also intended to reduce emissions of air toxics; this fact is not noted here. While most of the toxics emissions reduction comes from the control of fuel benzene content, the remaining reduction results primarily from the dilution of toxic-forming compounds (such as aromatics) upon the addition of the oxygenate.

See comment 2.

p.3 (Background) It was the Clean Air Act, not EPA regulations, that "set-up" the two-phase program for RFG. (EPA regulations implemented the specifics of the program which Congress outlined.)

Now on p. 3.

See comment 3.

p.4 (general) Early drafts of this study also addressed the wintertime oxygenated fuels program. This latest draft does not include this discussion, yet it is still reflected in the title. The oxygenated fuels program should be discussed as it was one of the key factors contributing to the growth of the use of oxygenates, but the current size of the program needs to be reflected. (Originally 39 areas were part of the program, but due to the success of the program the number of areas now participating is greatly reduced.)

Now on p. 3.
See comment 4.

p.4 (first full paragraph) The description of the oxygen requirement for RFG is incorrect, as the requirement is based on oxygen content by weight, not oxygen<u>ate</u> content by weight. The correct language would be: "...oxygenates must be added to gasoline **such that oxygen makes up** 2 percent of the finished product's weight."

Now on p. 4.
See comment 5.

p.5 (typographical error) "For example, **EPA** estimates..." not "...EPA**'s**...")

Now on p. 4.
See comment 6.

p.5 (bottom of page) The cost-effectiveness for VOC control under Phase I of the RFG program, based on the cost analysis presented in the Regulatory Impact Analysis, is not $5550/ton on average but about $265/ton on average. The $5550/ton figure represents the entire cost of the Phase I program, including the oxygen requirement and the benzene reduction requirement (both of which contribute to the toxics reduction goal of the program). Neither of these two specifications contribute substantially to VOC reductions.

Now on pp. 4 and 5.
See comment 7.

p.6 (first full paragraph) Whether the subject regions of the country select RFG or low-RVP gasoline as a means to control VOC emissions, either program would be required throughout the region and thus all consumers in the region would be required to use that fuel. The requirement would be imposed on fuel providers, not on consumers. It is unfair to represent only one of the two programs as being required of consumers, and we would recommend that the phrase "...require consumers to use..." be stricken and the sentence be revised to read "...are considering whether to require RFG or gasoline with low vapor pressure."

Now on p. 5.
See comment 8.

p.6 (end of first full paragraph) EPA's Feb. 17, 1994 memo does not state that due to low volumes for low RVP fuel consumer prices may be higher than for RFG, but rather than prices may increase greater than the cost of production increases. The specific quote is "...consumer price increases might well exceed the increase in production costs for reduced volatility gasolines."

Now on p. 5.
See comment 9.

p.7 (general) EPA's estimates of the cost of Phase I RFG included an adjustment for the minor fuel economy loss that the consumer will experience due to the lower energy content of RFG. This cost would not be reflected at the pump as the refiners do not incur this cost, but rather would be paid by the consumer over time due to the need to purchase slightly more gasoline than before. Also, EPA's estimates were of the incremental **cost** of production, not of the **price** at the pump, which can include other factors ranging from taxes to retail markup, none of which are directly influenced by EPA's regulations. You may wish to note these facts in your text.

Now on pp. 5 and 27.
See comment 10.

p.7 (first full paragraph) While it is true that the average price increase for RFG over the course of the program has been about 7 cents/gallon, presenting this figure gives a skewed vision of the actual costs of the program. In fact, for most of the program the price differential has been 3-5 cents/gallon more than conventional gasoline (as you indicate on page 32). The average you calculated is higher because of the price spikes as high as 12 cents/gal experienced at the start of the program. Over time, the average will drift closer to the current cost. We recommend that you delete the reference to the average cost of the program from this page.

Now on p. 6.
See comment 11.

p.7-8 As noted in the cover letter, the oxygenate requirements of the RFG program do not change over time. Since the start of the program, the number of areas participating in the program has remained fairly stable. Although EPA is currently working on options to allow greater flexibility for areas to opt-in to the program and is encouraging states to take advantage of these options, few states have yet indicated they will do so. In addition, the number of areas participating in the oxygenated fuels program, which requires the use of gasoline containing at least 2.7% oxygen in the cities with the greatest wintertime carbon monoxide problem, have been steadily decreasing as the program succeeds in bringing areas into attainment for CO. The one unknown about future growth in the use of oxygenates is the likely increase in the use of ethanol as E85 or E100. We would defer to DOE on this matter as they are responsible for implementing the requirements of the Energy Policy Act. We recommend, however, that the difference between what is required by EPA programs and what may occur depending on the assumptions made about future growth in oxygenate use be clarified rather than relying solely on the EIA predictions.

Now on pp. 6 and 7.
See comment 12.

p.9 (general) It is not clear what fraction of oxygenate use in the future is assumed to be ethanol. The production of ethanol uses a substantial amount of petroleum, as reflected in the April 1995 DOE study referenced in Appendix I. If EIA did not take this into consideration when projecting future oxygenate use, the amount of petroleum displaced in meeting EPACT's goals may be substantially less than you project.

Now on p. 8.
See comment 13.

p.10 (footnote 15) You refer to biodiesel as "clean burning." EPA has been provided limited data on testing done with biodiesel that shows increased NOx emissions from the use of the fuel unless adjustments are made to the engine. The biggest benefit of biodiesel appears to be the reduced emissions of particulates (PM-10) compared to petroleum-based diesel fuel.

Appendix I

See comment 14.

p.18 (general) The referenced DOE report also examines the greenhouse gas emissions associated with an RFG produced with ethanol, yet this information is omitted from the appendix and from Table I.1.

Appendix II

Now on p. 21.
See comment 15.

p.23 (first paragraph) The legislation for RFG specified the addition of **oxygen** not **oxygenates** at a minimum 2% by weight.

Now on p. 21.
See comment 16.

p.23 (general - first paragraph) EPA's estimate of the cost-effectiveness of NOx control was for Phase II of the program. (Phase I has no NOx reduction requirement but rather a requirement that NOx emissions do not increase.) The cost-effectiveness of toxics control you report is for Phase I of the program.

Appendix III

Now on pp. 5 and 26.
See comment 17.

p.31 (general) In presenting the various estimates of the increased price for RFG in Table III.1, it is important to note two things. 1) EPA's estimate is for the increased **cost** of producing RFG, not necessarily the increased **price**. 2) EPA's estimates for include an adjustment of about 2 cents/gal for the loss in fuel economy associated primarily with the oxygen requirement. Not all of the other organizations accounted for this adjustment. See also previous comment for p.7 (general) above.

Now on pp. 5 and 27.
See comment 18.

p.32 (bottom) The sentence about the price difference being closer to 3 cents/gal should be presented also in the body of the report, on page 7.

Appendix IV

Now on p. 28.
See comment 19.

p.34 (general, Table IV.1) EPA's Phase II RFG requirements are likely to increase the use of ETBE due to the more stringent VOC emissions reduction requirements. This is not reflected in Table IV.1. While it is true that ETBE production was nearly zero only a year or two ago, this fledgling industry is growing and is limited largely by the currently high price of ethanol relative to methanol. We expect that ETBE will have a larger share of the oxygenate market for RFG beginning in the year 2000.

Now on p. 28.
See comment 20.

p.34 (general) The analysis of the petroleum displaced by the use of oxygenated fuels should also reference the DOE report from April 1995, referenced in Appendix I. The DOE study is the most accurate analysis of the actual displacement of petroleum and fossil energy due to the use of oxygenates. The EIA projections represented in the Annual Energy Outlook may not be representative of what will really occur, largely due to simplifying assumptions included in the EIA models which do not reflect programmatic requirements or actual energy consumption to produce oxygenates. For example, the petroleum used to produce oxygenates, as indicated in the footnote to Table IV.1. Furthermore, while EPA is working to provide greater flexibility for areas to "opt-in" to the program and hopes that several states will take advantage of this option, we have no indication that enough areas will opt-in to have result in a significant increase in the amount of oxygenates used in RFG. See also the comments for pages 7-9 above.

Glossary

Now on p. 60.
See comment 21.

p.51 (On-board automobile emissions diagnostic equipment) The definition of this is not quite right as the system isn't designed to measure emissions. A more accurate definition of on-board diagnostics would be "Technology on vehicles that allows an on-board computer to detect and record malfunctions in the emission control system, allowing more effective repair of vehicles with high VOC and NOx emissions."

Now on p. 61.
See comment 22.

p.52 (Tier 1 emission standards...) The Tier 1 standards also include emission standards for NOx and CO, not just VOC.

Now on p. 61.
See comment 23.

p.52 (Tier II emission standards...) The first sentence is incorrect, Tier II is not similar to California's LEV program. Rather, Tier II standards are described in the Clean Air Act Amendments of 1990, section 202(i). The remainder of the definition is correct.

The following are GAO's comments on the Environmental Protection Agency's letter dated May 17, 1996.

GAO's Comments

1. We agreed with this comment and have revised the report.

2. We agreed with this comment and have revised the report.

3. Our report refers to the use of oxygenated fuels to reduce carbon monoxide emissions. We revised the report to reflect EPA's comment that the number of areas participating in the oxygenated fuels program have been reduced.

4. We agreed with this comment and have revised the report.

5. We agreed with this comment and have revised the report.

6. According to EPA's regulatory impact analysis and discussions with EPA officials, $5,550 reflects the total cost of phase I of the RFG program. We added EPA's views on the costs of reducing VOCs to our report.

7. We agreed with this comment and have revised the report.

8. We revised the report to more clearly reflect EPA's position stated in its memorandum.

9. We agreed with this comment and have revised the report. (This comment relates to comment 17.)

10. We agreed with this comment and have revised the report.

11. The assumptions used for EIA's projected oxygenate use is explained in the agency comments section of this report. EIA's projections of oxygenate use do not include the future use of ethanol as an alternative fuel.

12. We said in our report that the petroleum displacement estimates do not account for differing amounts of petroleum that may be used in the production of ethanol and other types of oxygenates. We also said that the extent to which petroleum will be used to produce oxygenates depends on several variables and, therefore, is difficult to predict. According to EIA officials, factors affecting the extent of petroleum use to produce oxygenates include the type of oxygenate and different assumptions about

the source of raw materials and the energy used to produce the oxygenates and the vapor pressure of the blended fuel. We also pointed out that the greater amount of petroleum that is used to produce oxygenates, the less petroleum will be displaced. More detailed information on the extent of petroleum used to produce oxygenates can be found in the Argonne National Laboratory's April 1995 report referred to in appendix I.

13. We agreed with this comment and have revised the report.

14. We did not omit the greenhouse gas emissions associated with RFG produced with ethanol, as indicated by EPA. The table shows RFG with existing and new sources of ethanol as stated in notes b and c.

15. We agreed with this comment and have revised the report.

16. We agreed with this comment and have revised the report.

17. We agreed with this comment and have revised the report to explain EPA's RFG estimates.

18. We agreed with this comment and have revised the report.

19. We agree that EPA's phase II RFG requirements are likely to increase the use of ETBE due to the more stringent VOC emissions reduction requirements. The increase in ETBE use did not show up in the year 2000 because the lowest amount of oxygenate usage reflected was 1,000 barrels per day. However, EIA's forecast of oxygenate use to the year 2015 shows that ETBE usage increases after the year 2000. In fact, the table shows that 28,000 barrels per day of ETBE is predicted to be used in 2010.

20. See comment 12 above, which relates to this issue. We revised the note to table IV.1 to reflect that petroleum displacement would be lower given the extent of petroleum used to produce the oxygenates, as previously stated in the letter, and referred the reader to the Argonne National Laboratory report for further information on this issue.

21. We agreed with this comment and have revised the report.

22. We agreed with this comment and have revised the report.

23. We agreed with this comment and have revised the report.

Comments From the Department of Agriculture

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

DEPARTMENT OF AGRICULTURE
OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20250

16 MAY 1996

Mr. Victor S. Rezendes
Director
General Accounting Office
Energy, Resources, and Science Issues
Resources, Community, and Economic Development Division
441 G Street, N.W., Room 1842
Washington, D.C. 20548

Dear Mr. Rezendes:

We appreciate the opportunity to participate in the review of the General Accounting Office (GAO) draft report entitled, *MOTOR FUELS: Issues Related to Reformulated Gasoline, Oxygenated Fuels, and Biofuels.*

The conclusion of our review in the Department of Agriculture (USDA) is that the report does not focus sufficiently on the cost effectiveness of the reformulated gasoline program and the use of fuel oxygenates. At a time when gasoline prices are rising, and public health advocates are questioning the effectiveness of our air pollution standards and pollution mitigation programs in preventing disease, the information available to the public and local officials about these programs is often confusing and contradictory. With this report, GAO has an opportunity to influence the public debate by analyzing competing information and providing an objective evaluation of the costs and benefits of reformulated gasoline and fuel oxygenates. From our perspective, the report does not sufficiently critique the cost effectiveness estimates that were examined.

Our detailed comments on the report are enclosed with this letter. If USDA can be of further assistance on this matter, please do not hesitate to contact me.

Sincerely,

KARL N. STAUBER, Ph.D.
Under Secretary
Research, Education, and Economics

Enclosure

UNITED STATES DEPARTMENT OF AGRICULTURE-COMMENTS

GAO-MOTOR FUELS: ***Issues Related to Reformulated Gasoline, Oxygenated Fuels, and Biofuels***

PAGE 4

Now on p. 3.

See comment 1.

- In the first full paragraph, the difference between oxygen and oxygenates should be clearified. The requirement is for oxygen to be added to reformulated and oxygenated gasoline; 2-percent by weight in reformulated gasoline and 2.7-percent by weight in oxygenated gasoline. Oxygenates are compounds that deliver oxygen to the fuel in various concentrations.

See comment 2.

- First full paragraph, last sentence, should explain that ethanol has been used in conventional gasoline as an octane enhancer and as a fuel extender.

PAGES 5 AND 6

Now on pp. 3-5.
See comment 3.

- All volatile organic compounds (VOC) are not equal. Throughout the report the cost effectiveness of different control measures is reported without regard to the ozone benefits of these control measures. There is also no mention of the benefits from reducing oxides of nitrogen (NOX) and toxic emissions that are also part of the reformulated gasoline program.

Now on pp. 4 and 5.
See comment 4.

- In the first full paragraph on page 6, the issue of toxic and NOX emissions should be addressed directly in the discussion of low-Reid vapor pressure (RVP) gasoline as a control strategy. The refining industry is claiming low RVP gasoline is a more cost-effective control strategy for VOC emissions, but what about the impacts on ozone that may occur by not controlling NOX? Moreover, there is no discussion of the fact that there is no control of toxic emissions from low RVP fuel. This should be stated directly.

Now on pp. 4, 5, and 22.
See comment 5.

- The assertion by the refining industry that low RVP fuel in more cost effective as presented on page 6 is not consistent with the claim made on page 24, table II.2 and on page 25, that the major reason for higher refining costs of Class B reformulated gasoline is the low-RVP requirement in Class B areas.

Now on p. 5.
See comment 6.

- Footnote, insert *from evaporation* before the period.

PAGE 7

Now on pp. 5 and 26
See comment 7.

- The estimates of the American Petroleum Institute (API) are far above those of other sources. When compared with the actual information collected by the Energy Information Administration (EIA), there is a question of whether API has overestimated the price effects that will be incurred by the industry. This discrepancy should be addressed.

Now on p. 5.
See comment 8.

- Retail prices for the first few months of the program should be reported, but not included as part of the price differential of the program over the life of the program. It is unlikely that prices for reformulated gasoline reflected long-run supply and demand conditions in the reformulated gasoline market during the first few months of program implementation because of the sheer size of the program. These initial adjustment costs should not be used to estimate the long-run costs of VOC reductions, because, in the short run, adjustment costs will have a large effect on the estimates of average costs per gallon of reformulated gasoline while, in the long run, the effects of adjustment costs will be overwhelmed by the observed price differentials associated with normal variations in supply and demand. Most knowledgeable analysts believe the incremental cost of reformulated gasoline is between 3 and 5 cents per gallon.

See comment 9.

- The costs estimates per ton of VOC reduction can be compared to estimates calculated using data reported by EIA. These calculations are made by using the 5-cents-per-gallon price differential and the VOC reductions predicted by the complex model to calculate the cost per ton of VOC emissions reductions. Our calculations indicate a cost of $3,100 per ton when cost due to price differences between conventional and reformulated gasoline is accounted for in VOC reductions, that is, NOX and toxic benefits are free. This estimate can be compared to the EPA's estimates of about $5,500 per ton for phase 1 reformulated gasoline and API's estimates that range as high as $10,000 per ton for VOCs alone .

PAGE 8

Now on p. 6.

See comment 10.

- In the second paragraph, GAO notes questions about the amount of petroleum used to produce oxygenates. This information should be available in USDA and DOE reports.

See comment 11.

- An important point that should be included in discussions of reformer severity is the gain in gasoline volume from reduced reformer severity. Both ARCO and Phillips have reported on the gains in gasoline volume attributed to the use of oxygenates and lower reformer severity.

See comment 12.

- Given the changes that occur in refinery configuration when oxygenates are introduced into the gasoline pool, the effects on the price of crude and gasoline from displacement by oxygenates as well as increased gasoline volume from lower reformer severity should be addressed.

PAGE 19

Now on p. 18.

See comment 13.

- The accounting methods used in greenhouse gas emissions studies have neglected to count the renewable CO_2 produced by renewable ethanol. How can a renewable fuel generate more greenhouse gases emissions than gasoline when the energy yielded by renewable fuels is greater than the energy used to produce them? A more thorough analysis of these issues is necessary.

Now on p. 20.

PAGE 21

See comment 14.

- The discussion of cost estimates is the most important issue in the report. The public wants to know if they are getting benefits from reformulated gasoline. Therefore the report should go further when discussing the benefits of control measures. For example, vapor recovery is relatively simple and cheap but it only removes low-reactivity compounds and does nothing to reduce high-reactivity tailpipe emissions. Therefore, vapor recovery may be a less effective ozone control strategy than reformulated gasoline. Enhanced inspection and maintenance is promoted as a cost effective control strategy, but the public may be subjected to substantial repair costs that are not included in the cost effectiveness calculations. Moreover, there has been considerable public resistance to implementation of enhanced inspection and maintenance programs in many States and few have been implemented. Finally, onboard diagnostics have no compelling enforcement that will require drivers to make necessary emissions system repairs.

Now on pp. 4, 5, and 22.

PAGE 24

See comment 15.

- Earlier in the report it was indicated that API argued for low-RVP gasoline as a cheap ozone control measure, now they are claiming RVP reduction is a major cost. How can these positions be reconciled?

Now on p. 23.

PAGE 26

There are several questions that need to be answered.

See comment 16.

- Does API's NOX cost estimates affect the winter PM benefits associated with NOX control?

See comment 17.

- How many tons are removed by each method?

See comment 18.

- Is API including modernization costs that improve refinery efficiency and reduce operating costs as part of these cost estimates?

Now on p. 26.

PAGE 31

See comment 19.

- It appears throughout the report that API estimates are about double those made by others and the evidence has shown them to be without foundation. A critical analysis of these estimates is needed.

Now on p. 27.

PAGE 32

See comment 20.

- As mentioned before, data from the implementation phase of the program should be reported and discussed, but not included in calculations of the average differential between conventional and reformulated gasoline because the data are essentially outliers.

See pp. 11 and 12 of the report.

GENERAL COMMENTS

We believe the report is weak on analysis. Many of the facts reported are well known to those following the issue, and this report does not add to this knowledge. The report does not provide conclusions about cost estimates of reformulated gasoline or its effectiveness as an ozone mitigation strategy. Currently API and others are promoting low-RVP fuels as the most cost effective ozone control strategy oftentimes using information without independent verification. GAO may be missing the opportunity to clarify several issues that are essentially accounting problems.

The following are GAO's comments on the Department of Agriculture's letter dated May 16, 1996.

GAO's Comments

1. We agreed with this comment and have revised the report.

2. We agreed with this comment and have revised the report.

3. The cost-effectiveness studies that we reviewed use VOC reductions as a proxy for ozone reductions. We state in our report that VOCs and NOx emissions are two of the more prevalent pollutants emitted by automobiles and are precursors to ozone pollution. We recognize in the background and other sections of the report that RFG helps to reduce VOC, NOx, and air toxics emissions.

4. We state in the referenced paragraph that RFG offers a number of benefits that low vapor pressure gasoline does not, including the reduction of air toxics and nitrogen oxides. We have revised this paragraph to make it clear that these benefits are in addition to VOC reductions, which are due in part to the lower vapor pressure of RFG.

5. This comment also responds to USDA's comment 15. Our report does not indicate that API believes that low vapor pressure gasoline is a cheap ozone control measure or that lowering the vapor pressure represents a major cost. In the text following table II.2 that USDA refers to, we point out that in cities that already use a low vapor pressure gasoline, the cost-effectiveness of adding a RFG requirement is higher. This is because some of the benefits of RFG was already obtained by using the low vapor pressure gasoline.

6. We agreed with this comment and have revised the report.

7. In this section, we gave the range of the price estimates for RFG compared to conventional gasoline prices—the low estimate cited by DOE and the high estimate cited by API. Appendix III.1 cites some of the reasons for the API higher price estimates. While API's estimate is in the high end of the range of estimates, it is largely within the range of prices actually experienced during the initial months of the RFG program. We agree, however, that to the extent API's estimated costs are higher than the actual costs experienced, its estimated costs to reduce pollutants would also be higher than actual.

8. We agreed with this comment and have revised the report.

9. While additional estimates of the cost-effectiveness of reformulated gasoline have been reported, and other estimates can be calculated, our objective was to identify and present cost-effectiveness data contained in major federal and other studies. Therefore, we made no change to the report.

10. We discussed this issue in detail with representatives from DOE and industry and concluded that varying industry practices make it difficult to assess the amount of petroleum used to produce oxygenates. As such, the displacement numbers presented likely represent the most petroleum displacement that can be expected. We revised the report to make this point clearer.

11. As our report indicates, the use of oxygenates could allow some refineries to operate their reformers at lower temperature, thus increasing the amount of gasoline produced. We also point out, however, that DOE, EIA, and industry officials believe that any such increases industrywide are likely to be relatively small.

12. Addressing potential price changes of crude oil and gasoline resulting from the displacement of crude oil by oxygenates was beyond the scope of our review. While there may have been some downward pressure on crude oil prices resulting from less demand as oxygenates were introduced, the overall impact on gasoline prices has been an increase in price as discussed in our report.

13. According to the author of DOE's Argonne National Laboratory study containing the information in question, USDA is incorrect in its position that renewable fuels such as ethanol necessarily emit fewer greenhouse gases than conventional gasoline.[1] The author pointed out that there are differing opinions regarding the amount of energy required to produce ethanol and that USDA's estimation is lower than that of EPA and DOE. According to the author, USDA's estimation of greenhouse gas emissions by reformulated gasoline neglect to account for a number of sources of carbon dioxide equivalent emissions resulting from the production and transport of the fuel. For instance, carbon dioxide emissions result from oil used by farming equipment, oil used to transport corn to ethanol plants, the production of fertilizer, and the burning of coal used in producing ethanol in processing plants.

[1]See footnote 1 in app. I.

14. Our report focused on the results of cost-effectiveness analyses done by EPA, API, Radian Corporation, and Sierra Research. We recognize in our report that a number of variables can affect the benefits and cost-effectiveness of the different measures for controlling VOCs and other air pollutants. We also point out that the costs and benefits across these studies are not measured uniformly, making it difficult to make comparisons among the control measures. However, the objective of our work was not to conduct our own analysis of the control measures, controlling for all the factors that may affect the results. We also discussed this issue in the agency comments section of our report.

15. See our response to comment 5.

16. The API study did not address whether the NOx cost estimates affect the winter particulate matter benefits associated with NOx controls.

17. The API study measured all VOC and NOx reductions in percentages rather than tons of reduction.

18. The API study did not indicate whether modernization costs were included as part of the cost estimates.

19. See our response to comment 7.

20. We agreed with this comment and have revised the report.

Objectives, Scope, and Methodology

The objectives of our review were to (1) summarize the results of federal and other studies on the cost-effectiveness of using RFG compared to other automotive emission control measures and compare estimates of the price of RFG used in such studies with more recent actual experience; (2) summarize the results of studies estimating the potential for oxygenates to reduce the use of petroleum; and (3) summarize the ongoing federal research into biofuels, including any related past or projected cost reduction goals, and any increased demand estimates based on such goals.

To identify studies on the cost-effectiveness of using RFG compared to other automotive emission control measures, we interviewed officials from EPA, DOE, USDA, the petroleum industry, associations representing the petroleum, oxygenated fuels, and renewable fuels industries, state and local government agencies, and others. Several organizations have conducted cost-effectiveness studies of air quality control measures. We examined those studies that (1) reviewed the cost-effectiveness of RFG as well as other mobile source control measures and (2) contained original analyses. The four studies listed in appendix II were the only studies we found that met these criteria. To compare estimates of the price of RFG used in such studies with more recent actual price experience, we used the price estimates used in the studies and obtained actual RFG prices reported by DOE's EIA.

To determine what estimates were available on the potential petroleum displacement through the use of oxygenates in gasoline, we interviewed officials from DOE, the refinery industry, and associations representing the oil and oxygenated fuels industries. Through these sources, we learned that DOE had the most comprehensive effort underway that would provide an estimate of the petroleum displacement potential by using oxygenated fuels. Accordingly, we obtained information on the use of oxygenates and its petroleum displacement potential from EIA and DOE's Office of Energy Efficiency and Alternative Fuels Policy. Because the Office had undertaken a study of the potential for replacement fuels to displace petroleum fuels by the years 2000 and 2010, we used those 2 years to show the estimated oil displacement from using oxygenated fuels.

We agreed with your office to identify any studies on the costs and benefits of using oxygenates versus aromatics as octane enhancers in gasoline and whether refiners were making appropriate cost comparisons between the use of oxygenates and aromatics. During this assignment, we informed your office that we had not been able to identify any such studies. According to the DOE officials we talked with, the petroleum refining industry and associations representing the petroleum industry, the costs and benefits of using oxygenates versus aromatics would vary greatly from refinery to refinery and are dependent on the economic and plant-capacity factors of each refinery. This makes it difficult to generalize about the appropriateness of refining decisions on using oxygenates or aromatics. Most of the officials we talked with, however, believed that refiners would act in their own economic interest in making this decision. We agreed with your office that no further work was needed on this issue.

To identify major federal research on biofuels, including any related production cost-reduction goals and the estimated use of biofuels based on such goals, we interviewed officials at DOE, USDA, representatives of the biofuels industry, and universities conducting biofuels research. We also met with officials at the Office of Technology Policy, Executive Office of the President; attended conferences related to biofuels; conducted literature searches; and reviewed and analyzed several reports and documents on biofuels. In addition, we interviewed officials at DOE's Oak Ridge National Laboratory and National Renewable Energy Laboratory, where DOE's most extensive biofuels research is conducted. We obtained information on past and projected cost-reduction goals achieved through biofuels research and development from officials at Oak Ridge National Laboratory, the National Renewable Energy Laboratory, DOE, and USDA. To identify the potential increased demand for biofuels, based on cost-reduction achievements, projections and goals, we obtained estimates on the demand for biofuels from DOE's National Renewable Energy Laboratory. We did not evaluate the methodology and assumptions the National Renewable Energy Laboratory used to arrive at the demand estimates cited in this report.

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Glossary

Aromatics

A class of high-octane hydrocarbons that constitute a certain percentage of gasoline. The chief aromatics in gasoline are benzene, toluene, and xylene. In addition to concerns about the toxicity of benzene, some aromatics are highly reactive chemically, making it likely that they are active in ozone formation.

Biodiesel

Biodiesel is a biofuel made from animal and vegetable derived oils that can be used as a substitute or additive to diesel fuel. According to EPA, the use of biodiesel may increase some types of emissions but reduce others.

Biofuels

Biofuels are alcohols, such as ethanol or other chemicals, derived from biomass or living matter. Current research is focused on developing biofuels from the starch in corn kernels or from the fibrous cellulosic materials in the rest of the corn plant; it also focuses on cellulosic plants, such as fast-growing trees or grasses, and waste products such as agricultural and forestry residues and municipal and industrial wastes.

Clean Fleet Vehicle Program

This program, starting in 1998, will require certain fleets (in certain nonattainment areas) of 10 or more vehicles, which can be centrally fueled, to meet clean-fuel vehicle volatile organic compounds (VOC) and nitrogen oxides (NO_x) emissions standards. These standards can be met through the use of alternative fuels such as compressed natural gas or through the use of reformulated gasoline (RFG).

Enhanced Automobile Emission Inspection and Maintenance Program

More stringent vehicle emission testing and repair program that is required to be implemented in areas in the United States with more serious air pollution problems.

Expanded Automobile Emission Inspection and Maintenance Program

An automobile emission inspection and maintenance program that requires testing more vehicles than required by EPA.

Ethanol

An alcohol produced from starch or sugar crops, such as corn or sugar cane, or from cellulosic biomass materials. Ethanol may be used as a fuel by itself (an alternative motor fuel) or blended into gasoline to increase the octane of gasoline and increase the gasoline supply. In the United States, ethanol has been largely blended in a 10-percent mixture with gasoline to form gasohol. As an oxygenate, ethanol supplies oxygen to gasoline, which reduces carbon monoxide emissions from vehicles. Because ethanol is water soluble, it must be blended into gasoline outside the refinery and it cannot be transported in the same pipelines with gasoline. In addition, ethanol increases the volatility of gasoline thereby increasing evaporative emissions. These drawbacks can be overcome if ethanol is converted to its ether form, ethyl tertiary butyl ether.

Ethyl Tertiary Butyl Ether (ETBE)

An ether compound made using ethanol, which is used as a gasoline additive to boost octane and provide oxygen. Since ETBE has low vapor pressure, it could be useful in helping to comply with volatility controls on gasoline. Unlike alcohols, ETBE could be produced and blended with gasoline at the refinery and shipped in gasoline pipelines.

Greenhouse Gases

Gases, including carbon dioxide, water vapor, methane, nitrous oxide, and chlorofluorocarbons, that when emitted into the atmosphere threatens to change the earth's climate.

Low Emission Vehicle Program

A California program that prescribes the maximum emissions permitted from new vehicles sold in that state.

Maximum Automobile Emission Inspection and Maintenance Program

More stringent automobile emission testing and repair program, which assumes that automobiles will meet appropriate emission standards over their useful life.

Methyl Tertiary Butyl Ether (MTBE)

An ether compound made using methanol, which is used as a gasoline additive to boost octane and provide oxygen to help reduce carbon monoxide emissions. MTBE is the most widely used oxygenate in RFG. Unlike alcohols, because MTBE could be produced and blended with gasoline at the refinery and shipped in gasoline pipelines, it is the most widely used oxygenate.

New Evaporative Standards and Test Procedures to Control Vehicle Emissions

New standards and test procedures that EPA is required to promulgate to control vehicle emissions under summertime, ozone conditions.

On-Board Automobile Emissions Diagnostic Equipment

Technology on vehicles that allows an on-board computer to detect and record malfunctions in the emission control system, allowing more effective repair of vehicles with high VOC and NOx emissions.

Oxygenate

The term applies to any gasoline additive containing oxygen. Oxygen in gasoline helps to reduce carbon monoxide, VOC, and air toxics emissions from vehicles. Oxygenates include alcohols, such as ethanol, and ethers, such as ETBE and MTBE. Each of these compounds also enhances the octane of gasoline, while their effects on volatility vary.

Reforming

Reforming is one refining process in which crude oil is converted into gasoline and other products.

Reformulated Gasoline

Gasoline whose composition has been changed through fuel reformulation. The Clean Air Amendments of 1990 requires certain fuel specifications and performance standards that RFG must meet to reduce air toxic and ozone-forming emissions in specified nonattainment areas. These areas are to start using RFG in January 1995 and in the year 2000, phase II RFG must be used, which further reduces VOCs, NOx, and air toxic emissions. California RFG requirements are stricter than the federal RFG requirements.

Refueling Vapor Recovery Equipment (Stage II)

This is a control measure for capturing the emissions of gasoline vapor during vehicle refueling and returning them to the storage tanks at service stations.

Reid Vapor Pressure Control

A control measure of gasoline volatility. Vapor pressure is expressed as pounds per square inch (psi) with higher pressure resulting in higher volatility of gasoline.

Tertiary Amyl Methyl Ether (TAME)

An ether compound made using methanol, which is used as a gasoline additive to boost octane and provide oxygen. Since it has low vapor pressure, TAME could also be useful in helping to comply with volatility controls on gasoline.

Tier I Emission Standards for Light-Duty Vehicles	National VOC, NOx, and carbon monoxide emission standards that light-duty vehicles are required to meet.
Tier II Emission Standards for Light-Duty Vehicles	Standards for certain light-duty vehicles and light-duty trucks to further reduce emissions. These standards would be more stringent national emissions standards that the federal government has the option of mandating beginning in model-year 2004.
Transitional Low-Emission Vehicle Program	A program that requires a portion of the California vehicle population to meet approximately 50 percent lower VOC emissions than the national VOC standards.
Ultra Low Emission Vehicle Program	A program that further lowers VOC emissions for the California vehicle population beyond that required in the transitional low-emission vehicle program.
Vehicle Scrappage Program	This program accelerates the removal of older vehicles from the fleet that have high mobile source emissions.
VOC/NOx Emissions	VOC and NOx emissions are two of the more prevalent pollutants that are emitted by motor vehicles and are precursors to the formation of ozone.
Zero Emission Vehicle Program	A California program that requires that by 2003, 10 percent of vehicles marketed in that state must be zero emission vehicles. Currently, the electric vehicle produces essentially no pollution from the vehicle's tail pipe or through fuel evaporation. Several other states have adopted zero emission vehicle requirements.

Related GAO Products

Gasohol: Federal Agencies' Use of Gasohol Limited by High Prices and Other Factors (GAO/RCED-95-41, Dec. 13, 1994).

Energy Policy: Options to Reduce Environmental and Other Costs of Gasoline Consumption (GAO/RCED-92-260, Sept. 17, 1992).

Air Pollution: Oxygenated Fuels Help Reduce Carbon Monoxide (GAO/RCED-91-176, Aug. 13, 1991).

Alcohol Fuels: Impacts From Increased Use of Ethanol Blended Fuels (GAO/RCED-90-156, July 16, 1990).

Gasoline Marketing: Uncertainties Surround Reformulated Gasoline as a Motor Fuel (GAO/RCED-90-153, June 14, 1990).

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