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Impact of the Renewable Oxygenate Standard for Reformulated Gasoline on Ethanol Demand, Energy Use, and Greenhouse Gas Emissions

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Impact of the Renewable Oxygenate Standard for Reformulated Gasoline on Ethanol Demand, Energy Use, and Greenhouse Gas Emissions

by Kevin C. Stork and Margaret K. Singh

Center for Transportation Research, Energy Systems Division,
Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439

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NOMENCLATURE AND DEFINITIONS OF TERMS

AEO	Annual Energy Outlook (EIA publication)
ANL	Argonne National Laboratory
API	American Petroleum Institute
bbl	barrel(s)
BD	barrel(s) per day
CAAA	Clean Air Act Amendments of 1990
CARB	California Air Resources Board
CG	conventional gasoline
CMSA	consolidated metropolitan statistical area (used by the U.S. Census Bureau)
CNG	compressed natural gas
CO	carbon monoxide
d or D	day(s)
DDGS	distillers dried grains and solubles
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EIA	Energy Information Administration (in DOE)
EtOH or ETOH	ethanol (a renewable oxygenate)
ETBE	ethyl tertiary butyl ether (renewable oxygenate produced from isobutylene and ethanol)
EV	electric vehicle
FHWA	U.S. Federal Highway Administration
FOE	fuel oil equivalent
g	gram(s)
gal	gallon(s)
gasohol	blend of 10 vol% ethanol with conventional gasoline
GHG	greenhouse gas
GWP	global warming potential
H ₂ or H2	hydrogen
HC	hydrocarbon
HD	heavy-duty
HDV	heavy-duty vehicle
HHV	higher heating value
IRI	Information Resources, Inc.
kcal	kilocalorie(s)
kWh or KWH	kilowatt-hour(s)
lb	pound(s)
LD	light-duty
LDV	light-duty vehicle
LNG	liquefied natural gas
LP	linear programming
LPG	liquefied petroleum gas
MBD	thousands of barrels per day
MeOH	methanol
mi	mile(s)
MM	million

MMM	billion
mo	month(s)
MT	metric ton(s) (2,200 lb)
MTBE	methyl tertiary butyl ether (nonrenewable oxygenate produced from isobutylene and methanol)
NG	natural gas
NGL	natural gas liquid
NMHC	nonmethane hydrocarbon
NO _x	nitrogen oxides (ozone precursors)
NPC	National Petroleum Council
NPRM	Notice of Proposed Rulemaking
OG	oxygenated gasoline (conventional gasoline meeting the federal OG requirement for CO nonattainment areas)
OPRG	oxygenate program reformulated gasoline
ORNL	Oak Ridge National Laboratory
O ₃	ozone (a pollutant)
PADD	Petroleum Administration Defense District
ppm	parts per million
PSA	Petroleum Supply Annual (EIA publication)
psi	pound(s) per square inch
RBOB	reformulated blendstock for oxygenate blending
RFG	reformulated gasoline
RIA	regulatory impact analysis (EPA publication)
ROS	renewable oxygenate standard
RVP	Reid vapor pressure (measure of gasoline volatility defined as the vapor pressure, in psi, of a 4:1 [by volume] air-to-fuel mixture at 100° F)
SEDR	State Energy Data Report (EIA publication)
SIP	state implementation plan
STEO	Short-Term Energy Outlook (EIA publication)
t	metric ton(s) (2,200 lb)
TAME	tertiary amyl methyl ether
TAP	toxic air pollutant
TM	Turner, Mason & Company
ton	short ton(s) (2,000 lb)
USDA	U.S. Department of Agriculture
VMT	vehicle mile(s) of travel
VOC	volatile organic compound
vol%	volume percent
wt%	weight percent

**IMPACT OF THE RENEWABLE OXYGENATE STANDARD
FOR REFORMULATED GASOLINE ON ETHANOL
DEMAND, ENERGY USE, AND GREENHOUSE
GAS EMISSIONS**

by

Kevin C. Stork and Margaret K. Singh

ABSTRACT

To assure a place for renewable oxygenates in the national reformulated gasoline (RFG) program, the U.S. Environmental Protection Agency has promulgated the renewable oxygenate standard (ROS) for RFG. It is assumed that ethanol derived from corn will be the only broadly available renewable oxygenate during Phase I of the RFG program. This report analyzes the impact that the ROS could have on the supply of ethanol, its transported volume, and its displacement from existing markets. It also considers the energy and crude oil consumption and greenhouse gas (GHG) emissions that could result from the production and use of various RFGs that could meet the ROS requirements. The report concludes that on the basis of current and projected near-term ethanol capacity, if ethanol is the only available renewable oxygenate used to meet the requirements of the ROS, diversion of ethanol from existing use as a fuel is likely to be necessary. Year-round use of ethanol and ETBE would eliminate the need for diversion by reducing winter demand for ethanol. On an RFG-program-wide basis, using ethanol and ETBE to satisfy the ROS can be expected to slightly reduce fossil energy use, increase crude oil use, and have essentially no effect on GHG emissions or total energy use relative to using RFG oxygenated only with MTBE.

1 INTRODUCTION

1.1 PURPOSE AND ORGANIZATION OF THIS REPORT

The Clean Air Act Amendments of 1990 (CAAA) call for the establishment of a reformulated gasoline (RFG) program. They require that, beginning on January 1, 1995, RFG replace conventional gasoline (CG) in the nine worst ozone nonattainment areas in the United States with a 1980 population of 250,000 or more (Section 211(k)). Moreover, state implementation plans (SIPs) may also require the use of RFG in other ozone nonattainment areas. The CAAA establish general requirements to be met by RFG with regard to its oxygen, benzene, and heavy metals content and its emissions of nitrogen oxides (NO_x). They also require that RFG meet the more stringent of either a formula or a performance standard

for volatile organic compounds (VOCs) and toxic air pollutants. The performance standards are more stringent for the year 2000 than for 1995.

The U.S. Environmental Protection Agency (EPA) has promulgated regulations to implement the RFG program (Final Rule, December 1993). It proposed a renewable oxygenate standard (ROS) when the RFG regulations were finalized. The ROS was finalized on June 30, 1994. The EPA's regulatory impact analysis (RIA) provides a more complete history and description of the ROS (EPA 1994a).

The ROS has been challenged in a lawsuit brought by the American Petroleum Institute (API) and other parties. In September 1994, the U.S. Circuit Court for the District of Columbia granted the plaintiffs a stay of the ROS until the case is decided. The effects of delays associated with the lawsuit on implementation of the ROS, if it stands, are unknown.¹

The ROS was adopted to assure a place for renewable oxygenates in the RFG program. The only renewable oxygenate expected to be used in significant volume in the near future is ethanol made from corn. Because oxygenation appears to be the most expensive aspect of Phase 1 RFG production (NPC 1993), any rule affecting the choice of oxygenates could have important consequences for the program as a whole.

This report analyzes the (1) impact that the ROS could have on the supply and transport of ethanol and on its displacement from existing markets; (2) energy and crude oil consumption associated with the production and use of various RFGs that could meet the ROS requirements; and (3) greenhouse gas (GHG) emissions of these RFGs. It also examines how mixed slates of RFGs that could satisfy the ROS would compare with RFGs oxygenated only with methyl tertiary butyl ether (MTBE) in their effect on the RFG program, especially with respect to energy, crude oil, and fossil energy production and use and GHG emissions.

The report updates and consolidates results of earlier Argonne National Laboratory (ANL) analyses conducted for the U.S. Department of Energy (DOE). These include analyses provided to EPA by DOE during deliberations over the ROS (Singh and McNutt 1993; Singh 1994a,b; Stork 1994a,b; others). It extends this earlier work by evaluating the RFG-program-level impacts of the ROS. Revisions of earlier versions of the analyses are discussed in Appendix A.

Sections 1.2-1.4 of this report briefly review the key elements of the RFG and ROS regulations. The balance of the report is devoted to the effects of the ROS. Section 2

¹ The underlying analysis for this report was completed before the lawsuit was filed and so does not reflect uncertainties associated with the lawsuit. If implemented, the ROS will require that 15% of the required oxygen be derived from renewable oxygenates during the first year and 30% be derived from them thereafter. Should the ROS eventually take effect, the timetable for implementing it will probably be moved because of the stay. However, the results presented for 1995 should still be generally valid for the first year of the program. This assumption is not a forecast and may prove to be invalid.

discusses its effects on the demand for and disposition of fuel ethanol.² Section 3 provides base-case estimates of per-gallon energy use (including total energy, fossil energy, and crude oil use) and GHG emissions from RFG. Section 4 contains alternative estimates of energy use and GHG emissions. Finally, Section 5 covers national-level energy use and GHG emissions attributable to RFG.

1.2 REFORMULATED GASOLINE REGULATIONS

1.2.1 Oxygen Content of Reformulated Gasoline

The CAAA require RFG to contain a minimum of 2.0 weight percent (wt%) oxygen. The final rule for the RFG program published by EPA allows refiners to meet RFG requirements on either a per-gallon or an average basis. The average standard is slightly more stringent than the per-gallon standard. The averaging standard for oxygen is greater than or equal to 2.1 wt% oxygen, with not less than 1.5 wt% in any gallon.

Averaging requires compliance surveys, which may be burdensome enough to cause refiners to meet some standards on a per-gallon basis. The minimum oxygen requirement is particularly easy to meet on a per-gallon basis because the oxygen content can be increased by adding more oxygenate — generally without adversely affecting other parameters for the batch of fuel (e.g., benzene is diluted when MTBE is added to finished gasoline).³

Before the final rule for the RFG program was promulgated, the National Petroleum Council (NPC) conducted a study of the capabilities of the domestic refining industry (NPC 1993). It suggested that a compliance margin (i.e., safety margin) would be necessary to assure that refiners attempting to meet the oxygen requirement on a per-gallon basis would actually meet the standard and avoid a penalty. This compliance margin — a 0.1 wt% oxygen operating margin above the required level — is an estimate of the average margin that the NPC believes refiners will use. Individual refiners could use larger or smaller compliance margins.

Gasoline sold in RFG areas⁴ that are subject to CAAA requirements for oxygenated gasoline (OG) must contain a minimum of 2.7 wt% oxygen during the winter carbon monoxide

² Ethanol considered in this report will always be fuel ethanol. Subsequent references to ethanol, with or without that designation, should be considered to refer to fuel ethanol.

³ In some cases, the effect of adding oxygenate is adverse, as it is when VOC emissions are increased because of the addition of ethanol.

⁴ RFG areas include mandated RFG recipients plus "opt-in areas," a term that is defined in Section 1.2.2.

(CO) control period and meet criteria as RFG.⁵ No compliance margin has been estimated for such RFG (designated as OPRG, oxygenate program reformulated gasoline).

1.2.2 Regional Coverage

In addition to the nine regions in which RFG is required (several cities in the Northeast and Chicago, Houston, Los Angeles, and San Diego), approximately 90 areas classified as serious or moderate ozone nonattainment areas in 1990 can join the RFG program to reduce their pollution. With EPA approval, these areas can join by a process known as "opt in." Opt in becomes effective one year after EPA approval is granted.

By June 1994, some of the 90 areas had joined. However, from July 1994 to the time the ethanol analysis was completed, no more opted in. Moreover, several of the areas that had opted in opted out of the program. These include all Pennsylvania counties outside the Philadelphia metropolitan area (a mandatory area); Jefferson County, New York; the Albany, New York, metropolitan area; the Buffalo, New York, metropolitan area; Hancock and Waldo Counties in Maine; and the June 1994 opt-in areas: Kewaunee, Manitowoc, and Sheboygan Counties in Wisconsin. The EPA has indicated that it will not enforce the RFG rules in areas that have opted out of the RFG program and will initiate a formal rulemaking process to officially allow them to get out of the program.⁶ RFG and oxygenate demand calculations in this report exclude gasoline consumed in the listed opt-out areas.

If population were to remain distributed according to 1991 patterns and if full opt in of the 90 areas were to occur, about 55% of the U.S. residential population would live in areas receiving RFG.⁷ Full opt in is unlikely, however, not only because some of the areas that had opted in are opting out, but because several potential opt-in areas have indicated they will not participate. For example, Missouri and Georgia SIPs indicate that low-volatility⁸ gasoline rather than RFG will be used in St. Louis and Atlanta. At the current opt-in level, about 30% of U.S. gasoline is reformulated.

⁵ In California, because of separate regulation by the California Air Resources Board (CARB), a per-gallon maximum oxygen content of 2.0 wt% is applied to all RFGs in order to avoid increased NO_x emissions. Although the CARB standards will not take effect until March 1, 1996, oxygen is restricted prior to that time under a waiver of federal CO-control standards. In New York, there is a similar oxygen limit of 2.7 wt%. Because of the unique nature of the California standards, no compliance margin is included when calculations for RFG sold in California are made.

⁶ The nine areas in which RFG is required under the CAAA may not opt out.

⁷ This 55% is exclusive of spillover from areas with RFG to areas not required to use it. Spillover will occur because the logistics system is not structured to deliver fuel in exact correspondence with ozone nonattainment area boundaries and because there is some commuting into and out of RFG areas. Most spillover estimates are 5% or lower. This analysis uses an estimated spillover of 1% for both reformulated and oxygenated gasolines.

⁸ Gasoline volatility is discussed in terms of Reid vapor pressure, which is the vapor pressure (in pounds per square inch) of a 4:1 (by volume) air-to-fuel mixture at 100° F.

1.3 RENEWABLE OXYGENATE STANDARD

The ROS requires that 15% of the oxygen in RFG in 1995 and 30% of the oxygen in RFG in subsequent years be derived from renewable oxygenates. The phase-in requirement was adopted because the EPA was concerned that ethanol production capacity in 1995 would not be sufficient to supply the total 30% of required oxygen unless some ethanol were diverted from current uses (e.g., in gasohol). However, the EPA does expect that capacity will be sufficient to meet the 30% renewable requirement in 1996 and thereafter.

1.4 OXYGENATES

Differences in total energy use, fossil energy use, crude oil use, and GHG emissions that result from using different RFGs meeting the same performance standards arise for a number of reasons. The oxygenates used to provide the oxygen content required for RFG vary in density, energy content, mass fraction of oxygen, and volatility, and the GHG emissions and energy use associated with their production and use differ as well. The oxygenates also affect the volume and composition of the hydrocarbon (HC) portion of the RFG.

1.4.1 Renewable Oxygenates

There are two criteria that oxygenates must meet to be classified as renewable under the ROS (see EPA 1994a for more details). First, the oxygen source must be renewable. Renewable oxygenates may either be directly blended (e.g., ethanol) or derive their oxygen from a renewable-oxygenate feedstock (e.g., ethanol feed to an ETBE [ethyl tertiary butyl ether] production process). Second, the oxygenate must not have commingling effects if it is to be used to satisfy the renewable requirement during the summer. Commingling effects are nonlinear increases that occur in the Reid vapor pressure (RVP) of RFGs of different composition after they have been mixed.⁹ Increased RVP contributes to increased evaporative emissions of VOCs.¹⁰ Concern with commingling effects arose during a previous attempt, under the Bush administration, to provide incentives for the use of ethanol in RFG. It was

⁹ The resulting RVP of the mixture of different RFGs is higher than the arithmetically weighted average of the RVPs of the components of the fuel mixture. Therefore, although it may be more precise to speak of adverse commingling effects, the term "commingling effects" is generally understood to refer to the nonlinear RVP increase, so that interpretation is used in this report.

¹⁰ High RVP can also increase HC and CO exhaust emissions, especially during cold start. Automotive emission control systems are designed for a specific fuel (indolene, since the emissions certification tests employ it). Using a different fuel (or different operating conditions) from the test will affect emissions. Cold-start emissions can be increased by high-RVP fuels because the car runs overly rich under this condition. Thus, the ratio of oxygen to fuel is lower than stoichiometric (i.e., there is less oxygen available than is necessary for complete combustion). The reason that RVP is controlled in the summer, however, is to avoid increased evaporative emissions.

partly responsible for the rejection of the proposal. (This idea was proposed in 58 FR 11722, Feb. 26, 1993.)

Under the ROS, ethanol use that contributes toward the satisfaction of the renewable requirement will be restricted to the time outside the VOC-control period (including the two transitional, or shoulder, seasons). ETBE is a potential renewable oxygenate for the summer because it does not cause an increase in RVP when blended with gasoline and does not exhibit commingling effects.¹¹ The renewable-use season will be referred to henceforth as "winter."¹² The VOC-control period will be referred to as "summer." This study assumes that all ethanol used as an oxygenate for RFG will be used during the winter.¹³

1.4.2 Likely Near-Term Oxygenates

A number of different oxygenates can be used in RFG, including various alcohols and ethers. Several of the most important oxygenates, as evidenced by their explicit inclusion in the EPA's Complex Model for RFG certification, are MTBE, ethanol, ETBE, and tertiary amyl methyl ether (TAME). This report considers ethanol and ETBE to be renewable oxygenates and MTBE as currently produced to be nonrenewable. RFGs oxygenated with TAME have not been analyzed. MTBE and ethanol are considered the most likely candidates for use in the first several years of the program.

ETBE has lower volatility than MTBE. ETBE's production cost relative to MTBE is largely a function of the relative prices of methanol and ethanol. For purposes of this analysis, it is assumed that before the year 2000, ETBE will generally be prohibitively

¹¹ The blending RVPs of ETBE, MTBE, and ethanol are 4, 8, and 18 pounds per square inch (psi), respectively. Of the three fuels, only ethanol has commingling effects. Blending RVP values depend on the composition of the HC blendstock and oxygenate concentration but are treated as constants in this report for comparison (NPC 1993, Volume I, Table 3-22). Using lower-RVP oxygenates (such as ETBE during the summer) allows the blending of larger amounts of butane, a high-RVP component, which expands the volume of products derived from a barrel of crude oil. Whether additional blending of butane in the summer actually occurs depends on demand for butane for isobutylene production, direct fuel use (e.g., heating applications), and winter blending in gasoline.

¹² Ethanol can be used in the summer as an oxygenate without earning renewable credit. Such use would require a low-RVP HC blendstock.

¹³ Refiners have indicated that this assumption may not be strictly valid. The transition from ether-oxygenated to ethanol-oxygenated RFGs in the summer-to-autumn "shoulder" (transitional) season poses problems because of the hydrophilic nature of ethanol. Therefore, some refiners may choose to produce an HC blendstock for use with ethanol year-round.

expensive relative to MTBE¹⁴ and that in 2000 and beyond, when more stringent VOC control will be required, ETBE will be a cost-effective renewable oxygenate. The lower volatility of ETBE will help in the attainment of VOC emission targets. It is further assumed that MTBE will still be used in 70% of the RFG in the year 2000 and beyond. ETBE will be used as a renewable during the summer, and ethanol will be used during the winter.

1.4.3 Ethanol Demand

Ethanol has been used as an additive in gasoline since the 1970s. When it constitutes 10% of the volume of the blend (as typically encountered), the fuel is called gasohol. Each year, about 1.2 billion gallons of ethanol is currently used in gasoline.¹⁵ The RFG program and the ROS will greatly increase demand for ethanol. Concern about the near-term availability of sufficient ethanol to satisfy the demand under the ROS motivated the 15% phase-in for 1995.

Ethanol is a candidate as a potential neat or near-neat (E85) alternative fuel. Within the time frames considered in this analysis, little or no use of ethanol as an alternative fuel is expected.

1.4.4 Ethanol Supply

This analysis assumes that ethanol is made from corn, whether the ethanol is used as an oxygenate directly or as a feedstock for ETBE production. Ethanol produced from other sources (such as cellulose) would result in different energy use and GHG emission profiles. However, these alternative oxygenate sources are not considered because it is assumed that they would be uneconomical or contribute very little (in terms of volume) relative to corn-based ethanol for the period under analysis.

Supply estimates for this study were made on the basis of U.S. Department of Agriculture (USDA) data on operating production capacity and capacity that was under construction and expected to be available by early 1995. This analysis estimates that approximately 1.4 billion gallons of ethanol production capacity will be available in 1995.

¹⁴ Spot methanol prices underwent large swings in the six months from October 1994 to April 1995 — \$1.80 to \$0.45, a four-fold difference, per various issues of the *New Fuels Report* (1993-1994) — while ethanol prices were stable. The data have not been reanalyzed to account for these methanol price swings since the original analysis was performed. When the analysis was conducted, the price of methanol relative to ethanol was more stable.

¹⁵ The Federal Highway Administration (FHWA) collected gasohol sales data through 1992 on the basis of state tax revenue data. The 1992 data indicate that about 900 million gallons of ethanol are used in gasoline. The data underrepresent ethanol consumption, however, because some states tax gasohol and gasoline at the same rate and report commingled data. There has also been some growth in gasoline demand since 1992, and there may have been an increase in ethanol use as a fraction of the gasoline pool. These factors lead to a somewhat higher estimate of current fuel ethanol use than that reported by the FHWA in 1992.

The EPA estimates that 253 million gallons of additional winter ethanol capacity will be available by early 1996. This study adopts the EPA's estimate.¹⁶

¹⁶ On an annual basis, it scales up the EPA's estimate of incremental winter ethanol capacity to 462 million gallons.

2 RENEWABLE OXYGENATE STANDARD AND THE ETHANOL MARKET

2.1 INTRODUCTION

2.1.1 Motivation for the Study of Ethanol Supply

Three main concerns exist with respect to the ethanol supply and the ROS: the adequacy of supply, the interstate movement of ethanol (and its implications for credit trading), and the diversion of ethanol from existing use.

2.1.1.1 Adequacy of Ethanol Supply

Approximately 1.4 billion gallons per year of ethanol is currently available from domestic production (approximately 90,000 barrels per day). This production capacity represents current operating capacity plus facilities under construction at the time this analysis was initiated (December 1993).

The EPA has estimated that winter ethanol production capacity will expand by 253 million gallons by 1996. This figure corresponds to about 462 million gallons on an annual basis. The EPA RIA for the ROS also estimates a current excess winter capacity of 80 million gallons (EPA 1994, Table I-3, p. 13).¹⁷ The EPA does not provide an estimate of ethanol expansion beyond 1996. On the basis of the EPA's capacity expansion estimate, by 1996, about 1.6 billion gallons per year (106 million barrels per day) of ethanol capacity will be available.

The USDA (1988) has estimated that the upper limit of ethanol available from corn feedstocks is approximately 3 billion gallons per year, about twice the current capacity. This limit is derived from an estimate of the maximum amount of anticipated corn crops that can be dedicated to ethanol production. Year-to-year variations in crop yield may influence ethanol availability. Eventually, cellulosic ethanol or other renewable oxygenates may be an economic source of significant volumes of additional ethanol. It is assumed that this situation will not occur in the period under study.

The ROS will require an increase in the use of ethanol of about 380 million gallons per year over current levels, assuming that no ethanol is diverted from current uses outside of RFG areas and that current levels of gasoline demand remain the same. This figure

¹⁷ This report estimates a larger current excess ethanol capacity of about 100 million gallons per year. The difference between this report and the RIA occurs because this report relies on a lower estimate of ethanol use when the ROS is not applied and a similar production capacity estimate.

implies a total demand for approximately 1.6 billion gallons of ethanol. For the phase-in, approximately 80 million additional gallons of ethanol will be required.¹⁸

Although ethanol capacity can certainly be expanded in the future, and alternative sources of ethanol and other renewable oxygenates may become available in the longer term, during the debate surrounding the ROS rulemaking, the EPA, DOE, and others expressed concern about the adequacy of supplies of ethanol in 1995. Since ethanol can be used as a renewable oxygenate only during a portion of the year, seasonal as well as annual shortages may be of concern. Any annual shortage of ethanol may be exacerbated by the seasonality of the ROS.

2.1.1.2 Ethanol Logistics System

RFG is used primarily in areas that have not used much ethanol in the past. Thus, some incremental transportation of ethanol will be required under the ROS. Although this report is not a study of the logistics system, it includes an estimate of the volumes of ethanol that will need to be transported and diverted from current use to use in RFG as a result of the ROS. It also includes an assessment of the mitigating effect of credit trading on the necessity to transport incremental ethanol. Two assumptions are made:

- Transportation of ethanol or diversion of ethanol from other uses within a contiguous RFG area will impose no incremental transportation burden.
- Transportation of ethanol from non-RFG areas to RFG areas within the same state is ignored because the logistics system is sufficiently flexible to easily accommodate small changes in final destination.

2.1.1.3 Diversion of Ethanol from Current Use

The degree to which the use of ethanol in gasoline will increase as a result of the ROS will depend strongly on ethanol not being diverted from current use to meet the demand created by the ROS. The EPA adopted the phase-in of the ROS to avoid such diversion of ethanol from current use in non-RFG areas.

To establish boundaries for the impact of the ROS on ethanol demand, this analysis estimates the ethanol requirements of the ROS both considering and without considering

¹⁸ The additional ethanol required during the phase-in is not 190 million gallons per year (380 million gallons per year divided by two) under the given conditions because there is currently some ethanol used in RFG areas. This current use of ethanol constitutes a larger fraction of ethanol demand during the ROS phase-in than during the full program. During the 30% program, about 168% more ethanol will probably be used; during the phase-in, 34% more ethanol will probably be used. Therefore, incremental ethanol use will probably be five times larger during the remainder of the program than during the phase-in.

diversion. The preferential use of existing ethanol can lead to its complete diversion from current use in some of the scenarios examined. With no diversion, additional ethanol is required beyond the phase-in period. Intermediate cases between complete diversion and no diversion, while possibly most realistic, are not analyzed.

2.1.2 Renewable Oxygenate Credit Generation

Use of renewable oxygenates above the minimum level required under the ROS will result in the generation of negotiable renewable oxygenate credits. It is the responsibility of each refiner to meet the ROS requirement on a calendar-year basis. The unit of accounting for the renewable oxygenate requirement is weight percent-gallons (wt%-gal). This unit allows RFGs with different oxygen levels to contribute toward satisfying the renewable requirement, weighted by volume. Therefore, oxygenating to more than 2.0 wt% with renewables, or oxygenating more than 30 vol% of the RFG with renewables, or both, will result in credit generation.

In practice, refiners may use more ethanol than is required to achieve 2.0 wt% oxygen to allow for compliance margins or averaging. In an environment in which ethanol is in short supply, refiners are likely to try to trade the credits that they may generate. The credit market for the ROS is currently untested, however, and refiners in need of credits may be reluctant to rely on it to satisfy their renewable oxygenate obligations. This report assumes that credits can be sold and uses 2.0 wt% oxygen as the basis for calculating the demand for renewable oxygenates.

MTBE-oxygenated RFG is assumed to be at the 2.1 wt% level predicted in NPC (1993) because credit trading does not apply to nonrenewable MTBE-oxygenated RFG. Although this assumption affects demand for MTBE, this report simply assumes that there will be sufficient MTBE available to meet demand. In practice, this situation is likely in the near term only if some ethanol is used in RFG or if imports of MTBE increase substantially. It is clear that some ethanol is being used in RFG independently of the ROS.

2.2 METHODOLOGY

2.2.1 Demand for Reformulated Gasoline

RFG demand has been estimated by using population density to approximate gasoline demand. The fraction of each state's population residing within RFG areas is multiplied by the state's gasoline demand. One percent is added to account for spillover.

Gasoline demand projections from DOE's Energy Information Administration (EIA) have been used in this analysis, apportioned by fuel type. Projected 1995 demand was taken from EIA's Short-Term Energy Outlook (STEO) published in the second quarter of 1994. For later years, EIA's Annual Energy Outlook (AEO) published in 1994 was used.

National gasoline demand was distributed among states in proportion to the states' gasoline use reported in EIA's State Energy Data Report (SEDR) published in 1992. Seasonal changes in overall gasoline demand were not taken into account.

RFG volumes delivering equal energy vary slightly depending on the choice of oxygenate. To deliver an equal amount of energy, any RFG requires approximately 2% more volume than does conventional gasoline.

2.2.2 Gasoline and Ethanol Data Sources

State-level demand for finished fuels (RFG, OG, gasohol, and CG) and ethanol in 1995 is estimated by extrapolation from 1992 sales data on gasohol sales published by FHWA in 1993 and EIA historical gasoline consumption data¹⁹ (minus the gasohol). These data were then inflated to the appropriate years for the various time frames on the basis of EIA projections.

Gasohol sales are underreported in the FHWA data because they are based on tax revenue, and some states tax gasoline and gasohol at the same rate. In those states, gasohol is counted as part of the gasoline pool. Moreover, the data on total volume of gasoline and gasohol sales reported by the FHWA are larger than the EIA historical data for 1992. Thus, maintaining the *fraction* of total gasoline demand satisfied by gasohol in 1992 according to FHWA statistics and adjusting the total to agree with EIA data would worsen underreporting of gasohol. For this reason, the FHWA-reported *volume* of gasohol sold in 1992 is used as a basis and inflated for later years according to EIA projections of growth in total gasoline demand.

Ethanol production capacity estimates for 1995 are based on USDA data. The EPA's projection of additional capacity for 1996 is used for later years. All ethanol production facilities are assumed to operate at 85% of nameplate capacity.

2.2.3 Use of Ethanol in Nonreformulated Oxygenated Gasoline and Gasohol

The EIA reports that in 1994, about 30% of OG was oxygenated with ethanol. (This statistic presumably includes any OG demand satisfied by gasohol sales.) On the basis of the population of CO nonattainment areas that participated in the federal OG program during the 1993-1994 winter season,²⁰ this report estimates that there is a demand for about

¹⁹ In 1993, the EIA adjusted its statistic on the volume of gasoline supplied to include blend stocks and alcohols. A 1993-basis adjusted volume for 1992 was subsequently published and is the value used in this analysis to make the EIA data consistent with the FHWA data.

²⁰ A number of CO nonattainment areas have never participated in the OG program or have withdrawn from the program since the first season in which it was in effect (winter 1992-1993). It is possible that other regions will stop using OG in favor of other CO attainment strategies (e.g., enhanced inspection and maintenance), but it is unlikely that areas that have left the program will choose to use OG. Hence, this report uses the 1993-1994 winter program participation as a basis for estimating OG demand.

14 billion gallons of OG over an assumed average CO-control season of five months. About 65% of this demand is from areas that require RFG and would be satisfied by use of OPRG.

Data on the estimated volume of OG demand and the fraction of OG oxygenated with ethanol imply that there will be a demand for between 325 and 420 million gallons of ethanol for OG in winter 1995, without the ROS and the RFG program, depending on the amount of OG demand that is satisfied by gasohol. The lower number implies that 30% of OG is oxygenated to 2.7 wt% oxygen with ethanol (i.e., no OG demand is satisfied by gasohol). The higher number implies that 30% of OG is oxygenated to 3.5 wt% oxygen (i.e., all OG demand is satisfied by gasohol).

On the basis of data on gasohol sales by state and on ethanol use in CO nonattainment areas using OG, this report estimates that demand for ethanol in gasohol and OG would be 1.18 billion gallons per year without the ROS and the RFG program. For this calculation, ethanol was apportioned among the various OG areas according to data from the EPA and Information Resources, Inc. (IRI). EPA data were used to estimate ethanol use in the Northeast; IRI data were used for other areas. The total volume of OG oxygenated with ethanol according to this apportionment closely matches the aggregate estimate of EIA.

Of the 1.18 billion gallons of ethanol demand in the absence of the ROS and RFG program, 0.92 billion gallons per year would be used in gasohol, and 0.26 billion gallons per year would be used in OG at 2.7 wt% oxygen. The OG volume is the difference between total OG demand and the volume of gasohol expected to be sold in OG areas during the CO-control period. The tables in Appendix B contain the relevant data.

2.2.4 Seasonal Oxygenate-Use Case Descriptions

2.2.4.1 12-Month, Year-Round Case

The 12-month case represents the ethanol utilization rates that would result if refiners were to oxygenate year-round with renewable oxygenates (with ethanol during the winter and ETBE during the summer) to 2.0 wt% oxygen in 30% of the RFG (15% during the first year). The total volume of RFG differs slightly from that estimated on the basis of winter-only use of renewable oxygenates because of the differing densities and energy contents of ethanol and ETBE.

2.2.4.2 6.5-Month, Winter-Only Case

The 6.5-month case represents the use of ethanol only during the winter. The length of the season has been chosen to agree closely with the RIA estimate of a 197-day RFG

winter season.²¹ Because annual renewable oxygenate obligations are to be satisfied on a calendar-year basis, this case leads to a bipartite winter season. The first part runs from January through the end of March, and the second part runs from mid-September through the end of December, in agreement with the division of the year used in the RIA (EPA 1994a).

2.2.4.3 3-Month, Front-Loaded Case

The 3-month, or front-loaded, case represents an extreme in monthly ethanol demand in which refiners would attempt to satisfy annual renewable oxygenate obligations during the first part of the winter (Jan.-Mar.). Although it is unlikely that all refiners would do this, individual refiners, particularly those outside Petroleum Administration Defense District (PADD) II (Chicago area), might attempt to satisfy the ROS requirement during the first part of the winter season to avoid being caught short at the end of the year. Front loading effectively tightens ethanol supply during the first part of the winter. Some front loading is likely during the first year of the program because many refiners lack experience with ethanol and because the market for renewable-oxygenate credits is untested. A front-loaded case is also possible during future ethanol supply disruptions.

2.2.5 Time Frames Considered

The impact of the ROS on ethanol demand and disposition is analyzed in three time frames: the first year of the program (1995), near term (1996 through 1999), and long term (2000 and after). RFG program participation as of March 1995 is assumed for each time frame (as discussed in Section 1.2.2).

2.2.5.1 First Year

During the first year, the assumption is that there will be a 15% phase-in of the ROS, RFG demand will be at 1995 levels, and there will not be significant ETBE use. Two seasonal cases are considered in the first year of the renewable oxygenate program — winter only (6.5 months) and front-loaded (3 months).

The actual first year will probably be intermediate between the 6.5-month and 3-month cases. If ETBE is used more widely than assumed during the first year, summer may also be available for substantial use of renewable oxygenates, which would tend to lengthen the renewable season.

²¹ The effective winter season may be somewhat shorter in practice for some refiners. In particular, 6.5 months may be too long for Gulf Coast refiners serving markets in the Northeast.

2.2.5.2 Near Term

In the near term, the full 6.5-month winter season is assumed to be available for ethanol blending to satisfy the ROS (i.e., no front loading). It is assumed that ETBE will not be available in sufficient quantities for use as a renewable oxygenate in summer. RFG demand for 1995 is used for the near term to reduce the number of calculations and facilitate comparison with the first year.²²

It is likely that ethanol production capacity will expand over the period if the ROS goes into effect. Ethanol production capacity in 1996 is estimated on the basis of the RIA. Beyond 1996, ethanol capacity is assumed to be an unpredictable function of economic conditions.

2.2.5.3 Long Term

In 2000 and beyond, it is assumed that year-round oxygenation with renewables will be practical by using ETBE during the summer and ethanol during the winter. The Phase II RFG standards for VOCs will probably make ETBE attractive because of its low blending RVP. Data on RFG demand for the long term are derived from the EIA's data on projected gasoline demand for 2000.

Expansion of ethanol production capacity and an increase in the number of ethanol-to-ETBE facilities could occur between the present and the long-term time frame if the economics are favorable. The EIA's current unpublished forecasts for the 1995 AEO indicate a large and growing role for ETBE in 2000 and beyond.

2.2.6 Credit-Trading Analysis

Credit trading can reduce or eliminate the burden of ethanol blending on those refiners who prefer not to use ethanol. By relying on the credit market, however, refiners lose some control over the composition of their products, particularly toward the end of the calendar year when ROS credits must be balanced.

Credit trading is analyzed by distinguishing between those states likely to be net credit sellers and net credit buyers. This analysis assumes that refiners supplying RFG to PADD II RFG areas are the most likely net credit sellers, because consumers in that region are familiar with ethanol. Potential net credit buyers are assumed to be all others.

To assess the potential of credit trading to mitigate pressures of the logistics system, a maximum credit-trading scenario has been created, in which refiners supplying PADD II (i.e., the net credit sellers) have a surplus of renewable credits to trade. (PADD II states with

²² The EIA (1994 AEO) projects an increase in gasoline demand of approximately 5% over the near-term period.

RFG areas include Illinois, Indiana, Wisconsin, and Kentucky; the Chicago area is the major RFG market in PADD II). In these markets, the assumption is that 90% of the RFG will be oxygenated with renewable oxygenates to the maximum allowable oxygen level during the applicable season (i.e., ethanol to 3.5 wt% oxygen during winter; ETBE to 2.7 wt% oxygen during summer). States with RFG areas outside PADD II are assumed to use the minimum required level of ethanol in all RFG and to use no ethanol outside the RFG pool. The EPA has indicated that it "did not intend to give credit to renewable use in conventional areas" (EPA 1994b, Oct. 17, answer to Q6 under the heading "Renewable Oxygenate Program"). Therefore, the small (1%) spillover volume assumed in this analysis has not been included in the credit generation calculations.

It may be possible to use renewable oxygenates in more than 90% of PADD II RFG. However, particularly during the beginning of the program, outstanding MTBE contracts or other factors may constrain the use of renewable oxygenates. Maximum renewable use in this sense establishes the minimum necessary level of incremental ethanol movement.

2.3 RESULTS

2.3.1 Seasonal Analysis Results

Table 2.1 summarizes the net national supply of and demand for ethanol for each of the seasonal cases (12, 6.5, and 3 months) in each of the three time frames analyzed (first year, near term, and long term).

- Ethanol that would have been used within RFG areas in the absence of the RFG program is assumed to be used in RFG but is not counted in the calculation of diversion. On a 12-month basis, 224 million gallons of ethanol are being used within RFG areas without the ROS. The portion of this ethanol used during the winter, 121 million gallons, would apply toward meeting the ROS in the first year and near term. The full amount is credited as renewable for year-round renewable use in the long-term analysis.
- Estimated ethanol production capacity for 1995 is used for the first year; 1996 capacity is used for the near term and long term.
- Net supply implies that ethanol production capacity is in excess of demand. Net demand implies that ethanol production capacity is insufficient to meet demand.

The presentation of results for a 12-month renewable utilization period during the first year and near term is not meant to imply that year-round, renewable oxygenate use is expected during these periods. A longer ethanol blending season or early use of ETBE by some refiners could produce an intermediate case between the 6.5 month and 12-month cases.

TABLE 2.1 Seasonal Results^a

A	B	C	D	E	F
	Ethanol (10 ⁶ gal)				Ethanol to Be Diverted from Non-RFG Pool to Satisfy ROS (%)
Utilization Period for Ethanol in RFG (mo)	Production Capacity over Period ^b	Amount Required to Satisfy ROS	Demand outside RFG Areas over Period	Net Supply (Demand) over Period	
<i>First Year: RFG with 15% Renewables</i>					
12	1,368	300	959	108	0
6.5	741	300	520	(79)	15 ^c
3	342	300	240	(198)	83
<i>Near Term: RFG with 30% Renewables</i>					
12	1,830 ^d	601	959	270	0
6.5	991 ^d	601	519	(129)	25
3	457 ^d	601	240	(384)	>100 ^e
<i>Long Term: RFG with 30% Renewables</i>					
12	1,830	630	1,004	195	0
6.5	991	630	544	(183)	34

^a Columns A through D are either data inputs or calculated by the spreadsheet model; E = B - C - D; and F = the greater of -E/D and 0.

^b 1995 basis is used for first year; 1996 basis is used for near term and long term.

^c Small percentage diversion values should be considered in light of several potentially mitigating factors: inventory may be available to satisfy seasonal shortfall, inventory levels may change over time, season lengths may be slightly different than has been assumed, there could be more opt-out areas, and so on.

^d The EPA's projection of 1995-1996 winter ethanol production capacity expansion (EPA 1994a) — (250 million gallons of winter ethanol capacity — has been treated as 460 million gallons per year for the 12-month case to be consistent with the EPA's assumption about winter length (both values rounded).

^e Even though all ethanol would be diverted from the gasohol and OG pools, ethanol production capacity would not be sufficient to meet the requirements of the ROS in this case. Approximately 32% of additional ethanol capacity would be required to satisfy only the ROS over the period.

2.3.1.1 First Year

12-Month Analysis

- Over the period, there will be an excess of 108 million gallons of ethanol, given 1995 capacity and an unchanged level of ethanol demand in areas not using RFG during the 15% phase-in.
- If demand for ethanol in the gasohol and OG markets is not met, there will be an excess supply of 1.068 billion gallons.
- Meeting the ethanol demand that results from the RFG program would not require a reduction in use of ethanol for OG and gasohol during the period.

6.5-Month Analysis

- Over the period, there will be a shortage of 79 million gallons of ethanol, given current ethanol capacity and an unchanged level of ethanol demand in areas not using RFG.
- If demand for ethanol in the gasohol and OG markets is not met, there will be an excess supply of 441 million gallons.
- Meeting the ethanol demand that results from the RFG program would require a 15% reduction in use of ethanol for OG and gasohol during the period.

3-Month Analysis

- Over the period, there will be a shortage of 198 million gallons of ethanol, given current ethanol capacity and an unchanged level of ethanol demand in areas not using RFG.
- If demand for ethanol in the gasohol and OG markets is not met, there will be an excess supply of 42 million gallons.
- Meeting the ethanol demand that results from the RFG program would require an 83% reduction in use of ethanol for OG and gasohol during the period.

2.3.1.2 Near Term

12-Month Analysis

- There will be an excess of 270 million gallons of ethanol, given 1996 capacity and an unchanged level of ethanol demand in areas not using RFG.
- If demand for ethanol in the gasohol and OG markets is not met, there will be an excess supply of 1.229 billion gallons.
- Meeting the ethanol demand that results from the RFG program would not require a reduction in use of ethanol for OG and gasohol during the period.

6.5-Month Analysis

- Over the winter, there will be a shortage of 129 million gallons of ethanol, given expected ethanol capacity and an unchanged level of ethanol demand in areas not using RFG.
- If demand for ethanol in the gasohol and OG markets is not met, there will be an excess supply of 390 million gallons.
- Meeting the ethanol demand that results from the RFG program would require a 25% reduction in use of ethanol for OG and gasohol during the period.

3-Month Analysis

- Over the front-loaded period, there will be a shortage of 384 million gallons of ethanol, given expected ethanol capacity and an unchanged level of ethanol demand in areas not using RFG.
- Even if demand for ethanol in the gasohol and OG markets is not met, there will still be a shortage of 144 million gallons of ethanol to meet the ROS requirements (on the basis of the 1996 ethanol capacity level).
- Meeting ethanol demand that results from the RFG program would require the elimination of all ethanol in gasohol and OG during the period and an increase in production capacity of 32% (or an equivalent increase in inventory).

2.3.1.3 Long Term

Diversion is unlikely in this time frame, even for the 6.5-month season, because there is ample time to expand ethanol capacity or inventory. However, rather than forecast such expansion, the long-term analysis was conducted on the basis of estimated 1996 ethanol production capacity. Also, the front-loaded case was eliminated in the long-term analysis because it assumes that reliable ethanol supply patterns and an established credit-trading market will exist in a mature program.

2.3.2 Likely Program Operation

For the 15% phase-in for the first year, approximately 41% of 1995 winter ethanol capacity would be required to satisfy the ROS over a 6.5-month season. Of the ethanol use required to satisfy the ROS, 40% would be used in the absence of the RFG program in RFG areas. Ethanol use during the winter would increase by 2.5 times in RFG areas as a result of the ROS. Meeting ethanol demand due to the ROS as well as demand due to the use of gasohol and OG outside RFG areas would require about 80 million gallons of ethanol more than could be produced over the 6.5-month period.

The 6.5-month case, which represents the likely operation of the ROS during Phase I of the RFG program after the first year, would require utilization of about 61% of the ethanol production capacity at 1996 capacity to satisfy the ROS alone. This result suggests that capacity or inventory expansion will be necessary to avoid diverting the use of ethanol from gasohol and OG to RFG for the mature program.

If ethanol demand outside RFG areas were to be met, total ethanol demand during the 6.5-month period would be 1.120 billion gallons for the 30% program in the near term. This amount is approximately 13% more than 1996 production capacity over the period (991 million gallons) and so would require drawdown of inventory or additional expansion of capacity.

Ethanol stocks ranged from 75 to 120 million gallons during 1993 (EIA 1994, Table D.2). This figure suggests that a working inventory of about 50 million gallons would be available for drawdown. Meeting the demands of both the ROS and the gasohol/OG markets would require a 2.5-fold increase in working inventory if the shortfall over the 6.5-month period were to be supplied by using the inventory.

The long-term operation of the program does not appear to present significant supply or diversion problems.

2.3.3 Regional Analysis Results (Credit Trading/Ethanol Transport)

The results are summarized in Tables 2.2 and 2.3. The credit-trading analysis suggests that further study of the logistics system is warranted to determine the relevance of incremental ethanol transportation. Although volumes are reported in Tables 2.2 and 2.3,

TABLE 2.2 Maximum Generation of Credits^a

A	B	C	D
Ethanol (10 ⁶ gal) ^b			
Period of Credit Generation (mo) ^c	Maximum Used in PADD II RFG (90% of RFG at 3.5 wt%)	Required in PADD II under ROS ^d	Credit Available (equiv. wt%-gal)
<i>First Year: RFG with 15% Renewables</i>			
12	384	41	343
6.5	233	41	192
3	107	19	88
<i>Near Term: RFG with 30% Renewables</i>			
12	384	81	303
6.5	233	81	152
3	107	38	69
<i>Long Term: RFG with 30% Renewables</i>			
12	405	87	318
6.5	246	87	159

^a Column A = spreadsheet input; column B = 0.9 times the volume of ethanol required to oxygenate all PADD II RFG to 3.5 wt% oxygen (2.7 wt% during summer) over the period in column A; column C = 0.15 times the volume of ethanol required to oxygenate all PADD II RFG to 2.0 wt% oxygen over the period; column D = B minus C.

^b For 12-month cases, the ethanol equivalent of ETBE is reported for summer months.

^c It is unlikely that refiners in the ethanol producer states (in general, net credit sellers) will be limited to the 3-month period for generation of renewable oxygenate credits. However, credit purchasers could perceive a potential shortage of credits later in the year and be unwilling to risk waiting to balance their ROS credits. At some point, escalation in the price of ethanol would result in a reduction in near-term demand for ethanol (i.e., some refiners would decide that on the basis of market rates for ethanol, it would be worthwhile to wait until the second part of the winter season to buy ROS credits).

^d To balance credits in the 12- or 6.5-month cases, net-credit-selling refiners must fulfill the full year requirement for renewable oxygenate use over the period in question. Otherwise, in effect, they buy credits

Footnote d continued on next page

Footnote d from Table 2.2 (Cont.)

from themselves. Since the 3-month case arises as a result of a potential shortage of ethanol perceived by credit buyers rather than an actual shortage of ethanol, PADD II refiners can satisfy their ethanol demand over the 3-month period by using 46% of the yearly requirement and can sell the surplus. The assumption is that the rate of required ethanol use over both parts of the winter is constant. The credit market could be potentially more complex than this constant rate of credit accrual implies. For example, if ethanol prices were to rise in a front-loaded case, producer-state refiners might sell all their generated ROS credit speculatively and postpone taking ROS credits for their required volume of ethanol until the second part of the winter season.

TABLE 2.3 Net Ethanol Movement^a

A	B	C	D	E	F
Ethanol (10 ⁶ gal) ^b					
Period of Credit Generation	Gross Use Required to Meet Annual ROS outside PADD II	Available Credit from PADD II	Net Required outside PADD II under ROS	Current Use in RFG Areas outside PADD II	Incremental Transport to Satisfy ROS Only ^c
<i>First Year: RFG with 15% Renewables</i>					
12	260	343	-83	95	-178
6.5	260	192	68	52	16
3	260	88	172	24	148
<i>Near Term: RFG with 30% Renewables</i>					
12	519	303	216	95	121
6.5	519	152	367	52	315
3	519	69	450	24	426
<i>Long Term: RFG with 30% Renewables</i>					
12	544	318	226	95	131
6.5	544	159	385	52	333

^a Column A = data input; B = calculated by spreadsheet model; C = calculated in Table 2.2; D = B - C; E = calculated in spreadsheet model; and F = D - E.

^b For 12-month cases, the ethanol equivalent of ETBE is reported for summer months.

^c This accounts only for interstate movement from PADD II to other RFG states. Ethanol might be redistributed among states with and without RFG areas, and modes and distances of transportation might change under such redistribution.

the unit of renewable-credit accounting is wt%-gal. Physical units are reported for ease of use in the analysis of necessary incremental ethanol transportation. The credit-trading (and incremental transportation) results obtained when volumes are used as the unit of measure are the same as those calculated when wt%-gal is used (i.e., conversion of units is implicit). For example, in the 12-month case in Table 2.2 for the first year, maximum renewable use (with 90% of RFG oxygenated with renewables to 3.5 wt% during the winter and 2.7 wt% during the summer), as calculated from the 1995 PADD II RFG demand of 4.771 billion gallons, is 13.45 billion wt%-gal. During the first year (15% at 2.0 wt% oxygen), 1.43 billion wt%-gal is required, leaving 12.02 billion wt%-gal, or 89.4%, available for trade. This value agrees closely with the percentage available as calculated by using the volume-equivalent units reported in Table 2.2.

2.3.4 Conclusions

- There is likely to be diversion of ethanol early in the program, particularly if there is some front loading.
 - The front-loaded case would require nearly all the ethanol to be diverted during the 15% phase-in. In the case of a full 6.5-month winter ethanol blending season, satisfying the ethanol demand due to the ROS by use of production capacity only would result in a 15% diversion of ethanol from non-RFG markets. A combination of maximum inventory drawdown and full production capacity utilization would reduce diversion to 5%.
 - The ethanol required to meet the ROS would exceed the supply available from production and inventory in the front-loaded case for the 30% program in 1996. About 25% of the ethanol would need to be diverted during the 6.5-month ethanol season, at full use of production capacity but no use of inventory. With maximum inventory drawdown in addition to full capacity utilization, as little as 15% of the ethanol would need to be diverted over the winter.
- Diversion is unlikely in the long term because there is ample time for the expansion of ethanol production capacity and because front loading is unlikely in that time frame.
- Credit trading will not eliminate the need for some incremental ethanol transportation to RFG markets that had not used much ethanol before.
- A study of the ethanol logistics system will be necessary to determine the significance of increased ethanol transport to blending facilities in RFG areas that had not used much ethanol before.
- Ethanol production capacity or inventory will have to be expanded to satisfy ethanol demand related to the ROS.

3 ENERGY USE AND GREENHOUSE GAS EMISSIONS OF REFORMULATED GASOLINE

3.1 METHODOLOGY

3.1.1 Analytical Framework

Figure 3.1 shows the overall framework for the analysis described in this report. This analysis estimates the volume and type of feedstock (e.g., crude oil, alcohol, isobutylene) required for the gasoline and oxygenate components in each RFG. It estimates the process energy required to refine the crude oil to produce the HC portion of the finished RFG and the process energy required to produce the alcohols, isobutylene, and ethers for the oxygenates. It distinguishes the energy used to produce the RFG components and the energy embodied within the components from each other. Material and energy balances derived from these estimates allow the calculation of the composite energy and crude oil requirements of RFG oxygenated with MTBE, ethanol, or ETBE.

The GHG emissions of the various RFGs are also estimated. These estimates include GHG emissions associated with both the production of RFG feedstocks and the use of RFG. The evaluation of the energy and crude oil requirements and GHG emissions of the various RFGs is made on an equal-energy-delivery basis. The volume of each RFG is normalized, so that use of each fuel results in the same vehicle miles of travel (VMT).

3.1.2 Refinery Modeling

Two refinery models were used in this analysis to develop estimates of the energy and crude oil required to produce various RFGs. The Turner, Mason & Company (TM) refinery linear programming (LP) model was used to generate most of the refinery-related inputs to this study. The results of the TM refinery LP model runs were reported in the NPC (1993). Runs of a LP model used by Oak Ridge National Laboratory (ORNL) were used to derive the estimate of the energy required to produce winter RFG with ethanol.

The TM refinery LP model was used to model RFGs produced in a typical Petroleum Administration Defense District (PADD) complex refinery.²³ The district chosen (PADD II, Chicago area) is one of nine required to use RFG and a key market for ethanol sales. Although RFG production varies among PADDs, the general trend indicated in the results below would probably be the same for other PADDs. ORNL's model uses refineries in PADD III as its basis. PADD III includes Texas, New Mexico, Louisiana, Mississippi, Alabama, and Arkansas.

²³ NPC (1993) distinguishes between "simple" and "complex" refineries. Simple refineries have little or no ability to change the boiling range of the material they process. Complex refineries can convert material from one boiling range to another (EIA 1990, p. 8).

FIGURE 3.1 Overall Framework Employed in Analysis of Energy and Oil Requirements for RFG Production

The RFGs analyzed are year 2000 summer (VOC-controlled) and winter RFGs. They contain a minimum of 2.1 wt% oxygen (the averaging standard). The baseline fuel used in this analysis (base RFG) is summer RFG with MTBE, the oxygenate most likely to be used in the production of RFG. When compared with CAAA baseline CG, this RFG reduces VOC emission levels by 27-41%, depending on whether the February 1993 or April 1992 version of the EPA's complex model is used.²⁴ The EPA has developed this model for use in implementing the RFG program. The characteristics of this summer RFG with MTBE are indicated in Table 3.1. The refinery-related energy and crude oil inputs needed to produce this gasoline were calculated by TM.

Once the estimates for the summer RFG with MTBE were made, the constraints on the TM refinery LP model were changed to reflect a mixed RFG pool. In the mixed pool, 70% of the RFG uses MTBE as the oxygenate and 30% uses ethanol; both RFGs contain 2.1 wt% oxygen, the level that is consistent with the requirements of the February 1993 EPA Notice of Proposed Rulemaking (NPRM). (In the NPRM, the EPA proposed to allow RFG with ethanol to meet a less stringent VOC reduction standard.) The characteristics of this mixed RFG pool are also described in Table 3.1. The VOC performance of the mixed RFG pool was held to the original 41% reduction per the April 1992 version of the EPA complex model. The total energy content of the RFG produced daily (i.e., daily volume multiplied by specific energy content) and volumes and characteristics of key non-RFG products (e.g., diesel fuel) were held constant. The refinery model was allowed, within these constraints, to optimize production on the basis of cost. Energy and crude oil input requirements were then recalculated.

The TM refinery LP model was also used to estimate the energy and crude oil inputs needed to produce most of the winter gasolines considered in this study. TM developed estimates for winter CG and for a mixed pool of winter CG, OG, and RFG with MTBE as the oxygenate. VOC reduction is not specified since required VOC reduction applies only to the high ozone season. TM did not have an LP run with ethanol as a winter RFG oxygenate. The ORNL LP model provided estimates of the energy and crude oil inputs required to produce (1) a mixed pool of winter CG and RFG completely oxygenated with MTBE and (2) another mixed pool of winter CG and RFG oxygenated with both MTBE (70%) and ethanol (30%). Selected characteristics of the winter RFGs in these combined fuel pools are shown in Table 3.2.

From all these runs, estimates of the energy and crude oil input required to produce summer and winter RFG with MTBE and winter RFG with ethanol can be derived. The derivation is explained in Section 3.4. No runs assume use of ETBE as an oxygenate. Other available LP model runs that evaluated the energy and crude oil impacts of changes in the RVP of the HC portion of the RFG have been used to approximate the changes in the RFG

²⁴ This portion of the analysis was completed before December 1993, when the complex model was finalized. The VOC reduction of the baseline RFG used in this analysis has not been reestimated.

TABLE 3.1 Characteristics of Selected Summer RFGs Used in PADD II

Item	RFG with MTBE (Case S6)	Combined Pool of RFGs: 70% Use MTBE; 30% Use Ethanol (Case S13H)
Properties		
Aromatics (vol%)	23.9	23.6
Oxygen (wt%)	2.1	2.1
Olefins (vol%)	10.3	10
Benzene (vol%)	0.7	0.7
Sulfur (ppm by weight) ^a	236	86
RVP (psi)	6.6	6.8
T50 (° F) ^b	208	209
T90 (° F) ^b	342	327
EVAP at 200° F (%) ^c	47.8	47.4
EVAP at 300° F (%) ^c	81.5	84.8
Emission reduction from statutory base (%)^d		
VOCs	41	41
NO _x	0	5
TAPs ^e	33	39

^a ppm = parts per million.

^b T50 = temperature at which 50% of the gasoline sample evaporates. T90 = temperature at which 90% evaporates.

^c EVAP = percent evaporated at 200° F or 300° F, as appropriate.

^d Per the April 1992 version of the EPA's complex model. Fuel properties were set prior to the issuance of NO_x standards for Phase 2 of the RFG program (Phase 2 standards) and publication of the final complex model. To reduce NO_x sufficiently to make these RFGs comply with the NO_x standard would probably require further hydrodesulfurization, which could affect the energy and crude oil requirements and GHG emissions of the fuels.

^e TAPs = toxic air pollutants.

Source: NPC (1993, Volume 5, Table F-1).

TABLE 3.2 Characteristics of Selected Winter RFGs

Properties	RFG with MTBE in TM Case Q6W	RFG with MTBE in ORNL PADD III Analysis: All RFG Uses MTBE	RFG with MTBE in ORNL PADD III Analysis: 30% of RFG Uses Ethanol	RFG with Ethanol in ORNL PADD III Analysis: 30% of RFG Uses Ethanol
Aromatics (vol%)	18.2	25.2	25.0	23.2
Oxygen (wt%)	2.1	2.3	2.3	2.31
Olefins (vol%)	8.4	7.9	9.7	10.4
Benzene (vol%)	0.7	0.9	0.9	0.9
Sulfur (ppm by weight)	239	416	401	361
RVP (psi)	12.5	11.9	11.9	11.9

Sources: NPC (1993, Volume 5, Table F1-1A); ORNL (1994).

HC energy and crude oil input required to produce RFG with ETBE. This derivation is also explained.

3.1.3 Greenhouse Gas Emissions Modeling

The model used to develop the GHG coefficients for the various gasoline and oxygenate components was developed by Mark Delucchi²⁵ to estimate the GHG emissions of alternative motor fuels (DeLuchi 1991, 1993; Delucchi 1993). Delucchi's model accounts for GHG emissions from vehicle operation, vehicle manufacture, fuel production and distribution, and feedstock recovery and transport (the transportation fuel cycle). The type and amount of energy used at each stage of the fuel cycle are accounted for, as are the type and amount of GHG emissions at each stage. Non-CO₂ emissions are included and converted to a CO₂-equivalent basis by using updated global warming potentials (GWPs) of greenhouse gases. (GWPs convert mass emissions of non-CO₂ gases to the equivalent mass of CO₂ over an assumed period of time.)

Although Delucchi's model was designed to estimate the GHG emissions of alternative motor fuels, it can also be used to derive estimates of GHG emissions from the various components of RFG. Delucchi provides estimates of the GHG emissions associated with ethanol, methanol, CG without oxygenates, and a base RFG oxygenated with MTBE. Several runs of his model were made in this analysis to provide GHG coefficients for ethanol, MTBE, ETBE, and HCs. GHG emissions associated with vehicle manufacture were deleted from all estimates.

²⁵ Delucchi formerly spelled his name DeLuchi.

3.1.4 Normalization of Reformulated Gasolines to Deliver Equal Energy

The per-gallon energy content of various RFGs is different for a number of reasons. Different volumes of different oxygenates are required to produce a given oxygen content. Moreover, the energy content of various oxygenates is different. In this analysis, an oxygen content of 2.1 wt% and one of 2.7 wt% are of interest. ANL developed a spreadsheet model that normalizes the various formulations of RFG (and CG) to the energy content of the "base RFG" (summer RFG oxygenated with MTBE to 2.1 wt% oxygen). Once normalized, each fuel is capable of delivering the same VMT. For each fuel, the spreadsheet then calculates the energy, crude oil, and GHG emissions associated with delivering the same VMT as that delivered by the base RFG.

3.1.5 Key Assumptions and Inputs

Key assumptions and inputs for this analysis include the following:

- Gasolines were constrained to meet a NO_x standard for the year 2000 with a cost effectiveness of about \$10,000 per (summer) ton of NO_x reduced. This figure corresponds to an annual value of \$5,000 per ton of NO_x reduced. This constraint resulted in gasolines that are close to complying with the Phase 2 RFG standards (standards issued after the model runs were completed). Additional NO_x reduction would probably require additional hydrodesulfurization.
- All marginal changes in demand for isobutylene used to produce ether in merchant ether plants are derived from natural gas liquids (NGLs).
- Ethanol, methanol, and ether are produced as described in the sources cited in Section 3.4.

3.2 VOLUME OF RFG REQUIRED TO DELIVER EQUAL ENERGY

3.2.1 Reformulated Gasoline with 2.1 wt% Oxygen

RFG can be made by using various oxygenates (MTBE, ETBE, ethanol, TAME, etc.). The energy content of each oxygenate differs. Moreover, the various oxygenates replace different volumes of gasoline to achieve the same oxygen level in the RFG. As a result, the type of oxygenate used and its volume fraction in the RFG affect the energy delivered (per gallon) for vehicle propulsion. Table 3.3 provides estimates of the per-gallon energy delivered by various RFGs oxygenated with MTBE, ETBE, and ethanol. (In the table, the estimates assume Delucchi's base-case estimates of the energy and crude oil required to produce ethanol. See Section 3.4.3.)

TABLE 3.3 Fuel Volume and Energy Content of RFG with 2.1 wt% Oxygen and CG Based on Delucchi's Estimates of Energy and Crude Oil Required to Produce Ethanol^a

1	2	3	4	5	6	7
Fuel Type	Components	Initial Volume (gal)	Energy Content of Initial Volume (Btu)	Revised Volume to Deliver Equal Btu as Summer RFG with MTBE (gal)	Revised Energy Content (Btu)	Oil Content Feedstock (Btu)
<i>Summer</i>						
RFG with MTBE	HCs	0.885	101,275	0.885	101,275	101,275
	MTBE	0.116	10,799	0.116	10,799	641
	Total	1.000	112,075	1.000	112,075	101,916
RFG with ETBE (new EtOH) ^b	HCs	0.866	99,157	0.865	99,098	99,098
	ETBE	0.134	12,985	0.134	12,977	671
	Total	1.000	112,142	0.999	112,075	99,768
RFG with ETBE (existing EtOH) ^c	HCs	0.866	99,157	0.865	99,098	99,098
	ETBE	0.134	12,985	0.134	12,977	671
	EtOH	0.060	4,678	0.060	4,675	234
	CG	0.041	4,678	0.041	4,675	4,675
	Total	0.981	112,142	0.980	112,075	104,210
CG in PADD II (2 vol% MTBE)	HCs	0.980	112,210	0.963	110,237	110,237
	MTBE	0.020	1,870	0.020	1,837	1,032
	Total	1.000	114,080	0.982	112,075	111,269
<i>Winter</i>						
RFG with MTBE	HCs	0.885	99,683	0.897	101,120	101,120
	MTBE	0.116	10,799	0.117	10,955	0
	Total	1.000	110,482	1.014	112,075	101,120
RFG with ethanol (new EtOH) ^b	HCs	0.940	105,938	0.952	107,335	107,335
	EtOH	0.060	4,678	0.061	4,740	237
	Total	1.000	110,616	1.013	112,075	107,572
RFG with ethanol (existing EtOH) ^c	HCs	0.940	105,938	0.952	107,335	107,335
	EtOH	0.000	0	0.000	0	0
	CG	0.042	4,678	0.042	4,740	4,740
	Total	0.982	110,616	0.994	112,075	112,075
CG in PADD II (2 vol% MTBE)	HCs	0.980	110,446	0.978	110,209	110,209
	MTBE	0.020	1,870	0.020	1,866	413
	Total	1.000	112,316	0.998	112,075	110,622

TABLE 3.3 (Cont.)

1	2	8	9	10	11	12	13
Fuel Type	Components	Energy Required to Produce RFG (Btu)	Oil Required to Produce RFG (Btu)	Total Energy Required to Deliver RFG (Btu)	Total Fossil Energy Required to Deliver RFG (Btu)	Total Oil Required to Deliver RFG (Btu)	CO ₂ - Equivalent Emissions (g)
<i>Summer</i>							
RFG with MTBE	HCS	16,017	9,072	117,293	117,293	110,237	10,749
	MTBE	3,216	0	14,015	14,015	641	1,094
	Total	119,233	9,072	131,308	131,308	110,988	11,844
RFG with ETBE (new EtOH)	HCS	15,547	8,661	114,554	114,554	107,758	10,479
	ETBE	6,156	371	19,133	14,458	1,042	1,447
	Total	21,613	9,032	133,687	129,012	108,800	11,926
RFG with ETBE (existing EtOH) ^c	HCS	15,457	8,661	114,554	114,554	107,758	10,479
	ETBE	6,156	371	19,133	14,458	1,042	1,447
	EtOH	4,114	388	8,790	4,114	622	626
	CG	724	550	5,399	5,399	5,225	493
	Total	18,222	9,193	130,297	130,297	113,403	11,794
CG in PADD II (2 vol% MTBE)	HCS	17,069	12,960	127,306	127,306	123,197	11,634
	MTBE	467	0	2,305	2,305	1,032	186
	Total	17,537	12,960	129,611	129,611	124,229	11,821
<i>Winter</i>							
RFG with MTBE	HCS	13,481	7,984	114,601	114,601	109,104	10,279
	MTBE	3,318	0	14,273	14,273	0	1,110
	Total	16,799	7,984	128,874	128,874	109,104	11,389
RFG with ethanol (new EtOH)	HCS	14,435	8,656	121,769	121,769	115,991	10,933
	EtOH	4,171	393	8,911	4,171	630	635
	Total	18,606	9,050	130,680	125,940	116,621	11,568
RFG with ethanol (existing EtOH) ^c	HCS	14,435	8,656	121,769	121,769	115,991	10,933
	EtOH	0	0	0	0	0	0
	CG	668	487	5,408	5,408	5,227	488
	Total	15,103	9,144	127,178	127,178	121,218	11,422
CG in PADD II (2 vol% MTBE)	HCS	15,537	11,330	125,746	125,746	121,538	11,356
	MTBE	0	0	2,396	2,396	413	189
	Total	16,330	11,330	128,141	128,141	121,952	11,545

^a Energy, oil, and CO₂-equivalent emissions for RFG volumes that contain the same energy as RFG with MTBE.

^b New EtOH = incrementally produced ethanol as opposed to ethanol diverted from existing markets.

^c Existing EtOH = ethanol diverted from existing markets. Ethanol has a zero value in the winter existing ethanol case because the ethanol used in RFG is exactly offset by ethanol that has been diverted.

The RFGs in Table 3.3 are categorized as summer or winter fuels. Because of the VOC performance standard for summer RFG, and because ethanol is ineligible for ROS credit in the summer, only MTBE and ETBE are expected to be used to oxygenate RFG in the summer. Ethanol is quite likely to be used to oxygenate RFG in the winter and is therefore included in the winter fuel analysis section of the table.

Some of the estimates presented in Table 3.3 for RFG with ETBE and ethanol assume ethanol will be produced incrementally to the ethanol currently being produced in the United States (i.e., assume that additional ethanol beyond that currently being produced will be produced). This ethanol is henceforth called "new ethanol." Estimates of "existing ethanol" assume that the ethanol used in RFG (as either ethanol or ETBE) is diverted from current use. When ethanol is diverted, the net energy and crude oil effects related to ethanol production are zero, because the energy and crude oil savings that result from ending the production of ethanol for the original market are exactly offset by the energy and crude oil increases that result from producing ethanol for diversion to the new RFG market. However, the energy required to supply CG to replace ethanol in areas of the country from which it is diverted should be accounted for. Thus, the amount of CG that is sufficient to replace the ethanol energy in the RFG with ethanol or RFG with ETBE is included in the estimates of RFGs made with existing ethanol.

Column 2 of Table 3.3 lists the components of each gasoline that are of particular interest in this analysis: hydrocarbons, ethers, and ethanol. Column 3 presents the share of each of these components in a gallon of each gasoline type. This share is based on the volume of ether or ethanol required to meet the minimum 2.1 wt% oxygen content required of RFG; the source of these volume estimates is Table 3.4. Column 4 of Table 3.3 presents the energy content of a gallon of each gasoline type. The energy content is based on the share of each component in a gallon of gasoline (column 3) and the energy content (lower heating value) of each component, as presented in Table 3.5. Although the energy content of HCs used in RFGs varies slightly from one RFG to another, as demonstrated by the refinery LP runs, this analysis holds this energy content constant within each season.²⁶

Column 5 of Table 3.3 presents, for each gasoline type, the volume required to deliver the same total energy (see column 6) as that delivered by a gallon of base RFG. It is these fuel volumes that form the basis for the remaining analysis in this section. The

TABLE 3.4 Oxygen and Oxygenate Content of RFG

Oxygen Content in RFG (wt%)	Oxygenate Content (vol%)
2.1	13.4 ETBE 11.6 MTBE 6.0 Ethanol
2.7	17.2 ETBE 15.0 MTBE 7.7 Ethanol
3.5	10.00 Ethanol

²⁶ A sensitivity analysis was run to determine the effect of varying the summer fuel HC energy content. The effect was not significant with respect to the conclusions of the overall analysis reported here.

RFGs are actually very similar in terms of the volume of fuel required to deliver the same energy when the source of the ethanol is new ethanol. As expected, because RFG has more oxygen and consequently a lower energy content than CG, a greater volume of RFG is required.

3.2.2 Reformulated Gasoline with 2.7 wt% Oxygen

Table 3.6 presents, for winter RFG with an oxygen content of 2.7 wt%, estimates of the energy delivered by various RFGs and the volume required to deliver the same energy as that delivered by the base RFG. These winter RFGs will be used in areas that are CO nonattainment areas,

generally a winter problem. This fuel will comply with both the federal RFG program standards and the federal OG program standards. Again, the fuel volumes presented in column 5 are the basis for the analysis in the remainder of this section.

TABLE 3.5 Energy Densities of Oxygenates and Hydrocarbons

Item	Energy Content (Btu/gal) ^a
Ethanol (pure)	76,100
Ethanol (denatured)	77,970
Methanol	56,600
Isobutylene	94,000
ETBE	96,900
MTBE	93,500
Summer RFG HCs	114,500
Winter RFG HCs	112,700
Butane	93,000

^a Lower heating value.

3.3 FEEDSTOCK REQUIREMENTS: CRUDE OIL CONTENT

The crude oil content of RFGs varies because the volume of HCs in the different energy-equivalent RFGs varies and because the crude oil content of the oxygenates varies. Within this analysis, "crude oil content" means crude-oil-based material embodied in gasoline components (as feedstocks to the production process). Crude-oil-derived material consumed for energy in the production of fuel components, within or without refineries, is not considered crude oil content.²⁷ Thus, isobutylene made from crude oil would have a crude oil content, but ethanol made from corn (before the addition of denaturant) would not, despite the fact that over the fuel cycle, crude-oil derivatives are consumed (as process energy) to produce corn and ethanol.

Estimates of the shares of various components of gasoline that are considered to be crude oil are presented in Table 3.7. Their derivation is described here. Pure ethanol and methanol have no crude oil content in the sense defined above. Ethanol is denatured for use in fuel and thus contains some gasoline or crude oil (an average value of 5 vol% is assumed) or another denaturant. The feedstock for the HC portion of gasoline is assumed to be 100% crude oil. In fact, some natural gas (as hydrogen) and some NGLs are used as feedstocks, and their proportion in the final fuel may vary across gasoline formulations. This potential shift

²⁷ Crude oil consumed as process energy is tallied in column 9 ("Oil Required to Produce RFG") in Tables 3.3 and 3.6. The sum of "Oil Content (Feedstock)" (column 7) and column 9 is given in column 12 ("Total Oil Required to Deliver RFG").

TABLE 3.6 Fuel Volume and Energy Content of RFG with 2.7 wt% Oxygen and CG Based on Delucchi's Estimates of Energy and Crude Oil Required to Produce Ethanol^a

1	2	3	4	5	6	7
Fuel Type	Components	Initial Volume (gal)	Energy Content of Initial Volume (Btu)	Revised Volume to Deliver Equal Btu as Summer RFG at 2.1 wt% O ₂ with MTBE (gal)	Revised Energy Content (Btu)	Oil Content Feedstock (Btu)
RFG with MTBE	HCS	0.852	95,964	0.869	97,908	97,908
	MTBE	0.149	13,855	0.152	14,166	0
	Total	1.000	109,849	1.020	112,075	97,908
RFG with ethanol (new EtOH) ^b	HCS	0.923	104,045	0.940	105,975	105,975
	ETBE	0.077	5,988	0.078	6,099	305
	Total	1.000	110,033	1.019	112,075	106,280
RFG with ethanol (existing EtOH) ^c	HCS	0.923	104,045	0.940	105,975	105,975
	EtOH	0.000	0	0.000	0	0
	CG	0.053	5,988	0.054	6,099	6,099
	Total	0.976	110,033	0.994	112,075	112,075
CG in PADD II (2 vol% MTBE)	HCS	0.980	110,446	0.978	110,209	110,209
	MTBE	0.020	1,870	0.020	1,866	1,413
	Total	1.000	112,316	0.998	112,075	110,622

1	2	8	9	10	11	12	13
Fuel Type	Components	Energy Required to Produce RFG (Btu)	Oil Required to Produce RFG (Btu)	Total Energy Required to Deliver RFG (gal)	Total Fossil Energy Required to Deliver RFG (Btu)	Total Oil Required to Deliver RFG (Btu)	CO ₂ -Equivalent Emissions (g)
RFG with MTBE	HCS	13,053	7,730	110,961	110,961	105,639	9,953
	MTBE	4,291	0	18,457	18,457	0	1,435
	Total	17,344	7,730	129,418	129,418	105,639	11,388
RFG with ethanol (new EtOH) ^b	HCS	14,252	8,547	120,227	120,227	114,522	10,795
	ETBE	5,367	506	11,467	5,367	811	817
	Total	19,619	9,053	131,694	125,595	115,333	11,612
RFG with ethanol (existing EtOH) ^c	HCS	14,252	8,547	120,227	120,227	114,522	10,795
	EtOH	0	0	0	0	0	0
	CG	860	627	6,959	6,959	6,726	628
	Total	15,112	9,174	127,186	127,186	121,248	11,423
CG in PADD II (2 vol% MTBE)	HCS	15,537	11,330	127,746	125,746	121,538	11,356
	MTBE	530	0	2,396	2,396	413	189
	Total	16,067	11,330	128,141	128,141	121,952	11,545

^a Energy, oil, and CO₂-equivalent emissions for RFG volumes that contain the same energy as RFG with MTBE.

^b New EtOH = incrementally produced ethanol as opposed to ethanol diverted from existing markets.

^c Existing EtOH = ethanol diverted from existing markets. Ethanol has a zero value in the winter existing ethanol case because the ethanol used in RFG is exactly offset by ethanol that has been diverted

TABLE 3.7 Crude Oil Content of Fuels (Oil Embodied in Fuels from Feedstocks)

Fuel Type	Oil Content (%)	Ether and Isobutylene Production		Oil Feedstock for Isobutylene	
		Internal (share)	External (share)	Internal (share)	External (share)
Feedstock ethanol (pure)	0				
Fuel ethanol (denatured)	5				
Methanol	0				
HCs	100.0				
<i>Summer</i>					
Isobutylene					
For ETBE in RFG	7.5				
For MTBE only in RFG	7.5	0.075	0.925	1	0
For MTBE used with ethanol in RFG product mixes ^a	2.0	0.02	0.98	1	0
For MTBE in CG	71.0	0.71	0.29	1	0
ETBE	5.2				
MTBE only in RFG	5.9				
MTBE used with ethanol in RFG product mixes	1.6				
MTBE in CG	56.2				
<i>Winter</i>					
Isobutylene					
For MTBE only in RFG	0	0	1	1	0
For MTBE in RFG/CG mix	8.0	0.08	0.92	1	0
For MTBE in CG	28.0	0.28	0.92	1	0
MTBE only in RFG	0				
MTBE in RFG/CG mix	6.3				
MTBE in CG	22.1				

^a "Product mixes" are mixed pools of fuels. Individual batches of differently oxygenated fuels are segregated (e.g., ether-oxygenated and ethanol-oxygenated RFGs are segregated).

in feedstock is not accounted for. The NGLs themselves can be made from crude oil, thereby complicating the analysis of such a shift.

The crude oil content of ETBE and MTBE reflects crude-oil-based isobutylene feedstock in ether production. Isobutylene may be produced from crude oil or from NGLs. This analysis assumes that all isobutylene produced outside the refinery and used to make ethers outside the refinery is derived from NGLs. These NGLs are assumed to be derived from natural-gas-related sources. Isobutylene produced within the refinery is assumed to be produced from crude oil.

The derivation of the proportion of isobutylene used within the refinery to produce ethers is based largely on estimates developed in NPC (1993). For that study, TM developed estimates of the materials that would be used to produce various gasolines, both conventional and reformulated. Table 3.8 gives several TM estimates of the raw materials that would be

TABLE 3.8 Refinery Raw Materials and Products for Gasoline Used in PADD II in the Year 2000^a

Item	Summer Gasolines			Winter Gasolines			
	Base Case (No CAAA) ^b (Case Q9)	100% RFG (MTBE only) (Case S6)	100% RFG (30% EtOH) (Case S13H)	Base Case (No CAAA) (Case Q9W)	55% RFG/Rest CG (MTBE only) (Case Q6W)	62% RFG/Rest CG (MTBE only) (PADD III)	62% RFG/Rest CG (30% EtOH) (PADD III)
Products (bbl/d)							
Gasoline	1.682E+06	1.713E+06	1.717E+06	1.659E+06	1.681E+06	3.093E+06	3.092E+06
(% ether or ethanol)	2	12	10	2	8	8	7
Diesel	6.820E+05	6.820E+05	6.820E+05	6.820E+05	6.820E+05	1.324E+06	1.324E+06
Jet fuel	2.050E+05	2.050E+05	2.050E+05	2.130E+05	2.130E+05	7.704E+05	7.704E+05
Subtotal	2.569E+06	2.600E+06	2.604E+06	2.554E+06	2.576E+06	5.187E+06	5.187E+06
Plant fuel burned	2.306E+05	1.855E+05	2.007E+05	1.973E+05	1.769E+05	4.947E+05	5.019E+05
Other	3.620E+05	3.775E+05	4.293E+05	2.624E+05	2.540E+05	1.071E+06	1.041E+06
Total	3.162E+06	3.163E+06	3.234E+06	3.013E+06	3.007E+06	6.752E+06	6.730E+06
Production fuels							
Plant fuel burned (bbl/d)	2.306E+05	1.855E+05	2.007E+05	1.973E+05	1.769E+05	4.947E+05	5.019E+05
Natural gas purchased (FOE) ^c	3.290E+04	6.820E+04	7.090E+04	3.790E+04	4.710E+04	1.640E+05	1.640E+05
Electricity (kWh/d)	2.490E+07	2.330E+07	2.590E+07	2.190E+07	2.120E+07	0 ^d	0 ^d
Electricity FOE	4.021E+04	3.763E+04	4.183E+04	3.537E+04	3.424E+04	0	0
Raw materials for MTBE							
MTBE	1.000E+04	1.840E+05	1.390E+05	2.400E+04	1.166E+05	1.961E+05	1.254E+05
Methanol	8.000E+03	5.000E+03	1.000E+03	3.200E+03	3.200E+03	1.620E+04	1.530E+04
Total MTBE used	3.400E+04	1.990E+05	1.420E+05	3.360E+04	1.262E+05	2.447E+05	1.713E+05

^a Several results are presented for PADD III.

^b CAAA = Clean Air Act Amendments.

^c FOE = fuel oil equivalent.

^d There is electric power use in these cases, but electricity is generated on the refinery site, and the associated energy requirement is accounted for in the row labeled "Plant fuel burned."

Sources: Turner, Mason & Company for NPC (1993); Lax (1994); Hadder (1994); unpublished information.

used in the refinery to produce the MTBE needed for RFG and CG production. When MTBE is listed as a raw material, the assumption is that the MTBE (including its isobutylene feedstock) is produced outside the refinery. When methanol is listed as a raw material, the assumption is that crude-oil-based isobutylene (made within the refinery) is reacted with methanol to produce MTBE. Table 3.8 presents data on both summer and winter RFG. (The background data upon which this table is based are provided in Appendix C.)

For the base RFG (summer RFG oxygenated with 100% MTBE), it is estimated that 7.5% of the ethers would be produced within the refinery. For the summer RFG in which 70% is produced with MTBE and 30% is produced with ethanol, the TM estimates suggest that just 2% of the ether and isobutylene would be produced within refineries.

The estimated levels of internal ether production may appear low, but they are consistent with other process changes within the refinery related to the production of severely reformulated gasoline. Most important is the demand for C-4 olefins as feedstocks to the alkylation process; these olefins might otherwise be used for ether production. As the HC portion of the RFG is more severely reformulated to achieve additional VOC reductions to offset the higher RVP of ethanol-blended RFG, the refinery shifts further away from internal ether production.

No separate runs were performed by TM for RFG oxygenated with ETBE. This analysis assumes that the crude oil feedstock for the isobutylene used to produce ETBE is the same as that for the isobutylene used to produce MTBE. Because the alcohols used to make ETBE and MTBE differ, the fractions of crude oil in the ethers differ, as shown in Table 3.7.

TM provided two winter gasoline runs, but none with 100% RFG production. On the basis of the material presented in Table 3.8 for the two runs (Case Q9W and Case Q6W), Table 3.7 estimates that 28% of the MTBE produced for use in CG will be produced internally and 8% of the MTBE produced for an RFG/CG product mix of about 50-50 will also be produced internally. In terms of the volumes of methanol used as a raw material in gasoline production, the TM runs indicate that no additional methanol is used to produce the RFG/CG mix beyond the amount used for 100% CG production. Therefore, since the production of RFG did not increase the amount of MTBE produced internally, it is assumed that all the internal production of MTBE for the RFG/CG mix is assigned to CG and all the MTBE produced for RFG is produced externally. (As shown in Table 3.7, the MTBE used in winter RFG is estimated to contain no crude oil).

Results of two additional winter gasoline simulations are provided in Table 3.8. The simulations were developed to assess the amount of energy and materials required to produce winter RFG with ethanol. TM did not provide such an assessment; therefore, ORNL used its refinery model and PADD III data to provide the simulations. The results of these two runs were not used directly to analyze crude oil content, but an examination of the runs indicates that they, too, support estimates that significant amounts of the MTBE to be used in RFG are produced externally.

In column 7 of Tables 3.3 and 3.6, the crude oil content percentages derived in Table 3.7 are applied to all components of each RFG to develop a total estimate of the crude oil feedstock in each RFG. The tables reflect seasonal differences in crude oil content (for comparable fuels, winter is lower) and the fact that the crude oil content of RFG with MTBE is lower than that of CG.

When new ethanol is used, RFG oxygenated with ETBE uses less crude oil than the base RFG; RFG oxygenated with ethanol uses more.²⁸ Diversion of ethanol from current use causes both RFG with ETBE and RFG with ethanol to have a higher crude oil content than the base RFG. This result occurs because CG is substituted for the ethanol that has been diverted for use in RFG.²⁹

3.4 PROCESS ENERGY REQUIREMENTS

Estimates of the energy and crude oil required to produce the components of the various gasolines were derived from several sources. This section first addresses the production of the individual components and then discusses the total energy required to produce the final fuels.

3.4.1 Energy and Crude Oil Required to Produce Hydrocarbons

3.4.1.1 Hydrocarbons for Summer Fuels

As indicated, TM refinery LP model runs and two ORNL runs were used to determine the amount of energy and materials that would be required to produce various fuels. Table 3.8 summarizes the TM and ORNL results. These estimates were used to determine the amount of energy (plant fuel, natural gas, and electricity) and crude oil (plant fuel) required to produce the HCs used in RFG and CG.

²⁸ About 13.4% of the volume of HCs is replaced by ETBE at the 2.1 wt% oxygen level; MTBE replaces about 11.6% of HCs for the same oxygen content. Isobutylene feedstock for ether production is assumed to be 92.5% from natural gas sources and 7.5% from crude oil; feedstock ethanol and methanol contain no oil (ethanol feedstock is not denatured). On the basis of these assumptions, a larger amount of crude oil is probably replaced by ETBE than by MTBE.

When used as an oxygenate (rather than as a feedstock), ethanol replaces a smaller volume of HCs (6%) than does MTBE, and it contains a bit of crude oil in the denaturant. On the basis of these assumptions, ethanol-oxygenated RFG probably contains more crude oil than MTBE-oxygenated RFG. The relative crude oil content of these fuels appears in column 7 of Table 3.3.

²⁹ In the existing-ethanol cases, the crude oil content of the CG that replaces the ethanol diverted from CG to RFG is attributed to the oil content of RFG in column 7 of Table 3.3. The crude oil content of the diverted ethanol is deducted from the oil content of RFG but is much less than the crude oil from CG that replaces it.

The analysis of the energy and crude oil required to produce HCs assumes that all the plant fuel, natural gas, and electricity used in the refinery are used to produce the HCs for motor gasoline, diesel fuels, and jet fuel. These three fuels represent more than 75% of the products of the refinery. The diesel and jet fuel product volumes are then held constant over the various RFG and CG runs. All the runs result in the production of equal amounts of gasoline energy for vehicular propulsion. Any differences in the energy and crude oil required per gallon of HC produced are attributed to the different processing requirements of the various RFGs. The results of the analysis of the summer fuel runs are presented in Table 3.9. Some very small shifts in other products occurred, but these are not accounted for in this analysis.

As indicated in Table 3.9 and summarized in Table 3.10, little difference is estimated between the amount of energy required to produce HCs for summer RFG with MTBE and that required to produce them for CG, although less crude oil is required to produce the HCs used in RFG. The energy required to produce HCs for mixed RFG pool is greater than that required to produce them for RFG with MTBE only, because the HCs must be more severely processed to achieve the incremental VOC reductions needed to offset the VOC increase associated with ethanol use. Ethanol has a higher blending RVP than MTBE, which, if no other adjustments are made, increases the VOC level of the final fuel. Additional processing of the HC components is required to achieve a lower RVP level and maintain the same overall VOC level.

No refinery LP model runs for summer RFG with any ETBE mix were made. However, the use of ETBE in RFG should allow the refiner to use higher-RVP HCs (approximately 0.5 higher RVP), because ETBE has a substantially lower blending RVP than does MTBE. Use of these higher-RVP HCs should, at a minimum, lower plant fuel requirements below those for RFG with MTBE, because the lighter (higher-RVP) components can be used and additional processing to obtain lower-RVP components is not required.

An estimate of the amount of energy required to produce HCs for RFG with ETBE was derived by examining TM estimates of the energy required to produce two RFGs with a 0.4 RVP delta in their gasoline pool properties. The RVPs of the gasolines examined are 7.2 and 6.8. The amount of energy required to produce these RVPs may be greater than would actually be needed, but this situation is not relevant for this analysis, in which the focus is on the difference between the energy requirements of the two RFGs. Use of a 0.4 RVP delta rather than 0.5 RVP slightly understates this potential benefit of the use of ETBE. The TM runs examined were Case VLQ40 (V. Low Δ VOC) and Case LQ40 (Low Δ VOC); see Appendix C. PADD III runs were used in this analysis because similar runs were not made for PADD II.

This analysis estimates that an additional 250 Btu per gallon of HC produced is required to achieve the lower RVP. When this estimate is applied to the estimates of energy and crude oil required to produce HCs for summer RFG with MTBE, estimates of the energy and crude oil required to produce HCs for summer RFG with ETBE can be derived. These latter estimates are shown in Table 3.10.

TABLE 3.9 Plant Fuel Burned and Fuels Purchased to Produce HCs: Summer Gasolines (LP Runs Only)

Item	Base Case (No CAAA) (Case Q9) ^a	100% RFG (MTBE only) (Case S6)	100% RFG (30% EtOH) (Case S13H)
HCs produced			
Total HCs (bbl/d)	2.535E+06	2.400E+06	2.434E+06
Total HCs (gal)	1.065E+08	1.008E+08	1.022E+08
Diesel/jet only (bbl/d)	8.870E+05	8.870E+05	8.870E+05
Diesel/jet only (gal)	3.725E+07	3.725E+07	3.725E+07
Gasoline only (bbl/d)	1.648E+06	1.513E+06	1.547E+06
Gasoline only (gal)	6.923E+07	6.353E+07	6.497E+07
Total energy in plant fuel burned to produce HCs			
Total HCs (Btu)	1.433E+12	1.153E+12	1.248E+12
Diesel/jet only (Btu) ^b	5.015E+11	5.015E+11	5.015E+11
Gasoline only (Btu)	9.319E+11	6.516E+11	7.461E+11
Energy in plant fuel burned to produce HCs			
Total HCs (Btu/gal produced)	1.346E+04 ^c		
Diesel/jet only (Btu/gal produced) ^b	1.346E+04 ^c	1.346E+04	1.346E+04
Gasoline only (Btu/gal produced)	1.346E+04 ^c	1.026E+04	1.148E+04
Gasoline only (Btu/Btu HC produced)	0.118	0.009	0.100
Total energy in plant fuel burned, natural gas, and electricity to produce HCs			
Total HCs (Btu)	1.888E+12	1.811E+12	1.948E+12
Diesel/jet only (Btu) ^b	6.605E+11	6.605E+11	6.605E+11
Gasoline only (Btu)	1.227E+12	1.150E+12	1.288E+12
Energy in plant fuel burned, natural gas, and electricity to produce HCs			
Total HCs (Btu/gal produced)	1.773E+04 ^c		
Diesel/jet only (Btu/gal produced) ^b	1.773E+04 ^c	1.773E+04	1.773E+04
Gasoline only (Btu/gal produced)	1.773E+04 ^c	1.811E+04	1.982E+04
Gasoline only (Btu/Btu HC produced)	0.155	0.158	0.173

^a CAAA = Clean Air Act Amendments.

^b Energy in plant fuel burned, natural gas, and electricity to produce diesel and jet fuel is held constant across runs.

^c Energy in plant fuel burned, natural gas, and electricity to produce HCs in conventional gasoline is assumed to be the same for gasoline and diesel and jet fuel.

TABLE 3.10 Plant Fuel Burned and Fuels Purchased to Produce HCs: Summary

Fuels	Energy in Plant Fuel Burned, Natural Gas, and Electricity to Produce HCs (Btu/Btu HC Produced)	Energy in Plant Fuel Burned to Produce HCs (Btu/Btu HC Produced)
Summer		
CG	0.155	0.118
RFG with MTBE only	0.158	0.090
RFG with MTBE and EtOH	0.173	0.100
RFG with ETBE only	0.156	0.087
Winter		
CG	0.141	0.103
RFG/CG mix with MTBE	0.137	0.090
RFG with MTBE only	0.133	0.079
RFG with EtOH only	0.134	0.081

3.4.1.2 Hydrocarbons for Winter Fuels

The analysis of the energy and crude oil required to produce HCs for winter RFGs is based on the same general assumptions as those used for the summer fuel analysis, with some minor differences. Table 3.11 presents the analysis of the winter fuel runs. No winter runs resulted in 100% RFG. Therefore, to estimate the amount of energy and crude oil required to produce the HCs for RFG oxygenated with MTBE, the per-gallon energy required to produce HCs for CG was held constant between the all-CG case (TM case Q9W) and the RFG/CG-mix case (TM case Q6W). The result is that the amount of energy and crude oil required to produce HCs for winter RFG oxygenated with MTBE is lower than the amount required to produce HCs for winter CG.

To determine the energy and crude oil required to produce HCs for winter RFG oxygenated with ethanol, the results of the two ORNL refinery model runs were used. One run simulated production of a RFG/CG mix in which the RFG was oxygenated with MTBE only. Another run simulated the same RFG/CG mix, but with 30% of the RFG oxygenated with ethanol. A delta between the energy required to produce the HCs for the two mixes was derived and assigned to the energy required to produce HC for RFG oxygenated with ethanol only. This delta is extremely small. However, it was added to the estimates derived from the TM runs for the energy required to produce winter HCs for RFG with MTBE only. Estimates of the total energy required to produce HCs for RFG with ethanol resulted.

Table 3.10 presents summary estimates of the amount of energy and crude oil required to produce HCs for use in RFGs and CG. It shows that more total energy is required to produce HCs used in summer RFGs than to produce HCs used in CG. Less energy is required to produce HCs used in winter RFG, however. The amount of crude oil required

TABLE 3.11 Plant Fuel Burned and Fuels Purchased to Produce HCs: Winter Gasolines (LP Runs Only)

Item	Base Case (No CAAA) ^a (Case Q9W)	55% RFG/Rest CG (MTBE only) (Case Q6W)	RFG-MTBE Only (No case)	62% RFG/Rest CG (MTBE only) (PADD III)	62% RFG/Rest CG (30% EtOH) (PADD III)	Delta for RFG-EtOH Only	RFG-EtOH Only (No case)
HCs produced							
Total HCs (bbl/d)	2.520E+06	2.450E+06		4.942E+06	4.977E+06		
Total HCs (gal)	1.059E+08	1.029E+08		2.076E+08	2.090E+08		
Diesel/jet only (bbl/d)	8.950E+05	8.950E+05		2.095E+06	2.095E+06		
Diesel/jet (gal)	3.759E+07	3.759E+07		8.797E+07	8.797E+07		
Gasoline only (bbl/d)	1.625E+06	1.555E+06		2.848E+06	2.888E+06		
Gasoline only (gal)	6.826E+07	6.531E+07		1.196E+08	1.211E+08		
CG only (bbl/d)	1.625E+06	7.346E+05					
CG only (gal)	6.826E+07	3.085E+07					
RFG only (bbl/d)		8.205E+05					
RFG only (gal)		3.446E+07					
Total energy in plant fuel burned to produce HCs							
Total HCs (Btu)	1.226E+12	1.100E+12		3.075E+12	3.120E+12		
Diesel/jet only (Btu) ^b	4.355E+11	4.355E+11		1.303E+12	1.303E+12		
Gasoline only (Btu)	7.909E+11	6.641E+11		1.772E+12	1.817E+12		
CG only (Btu)		3.575E+11					
RFG only (Btu)		3.066E+11					
Energy in plant fuel burned to produce HCs							
Total HCs (Btu/gal produced)	1.159E+04 ^c			1.481E+04			
Diesel/jet only (Btu/gal produced) ^b	1.159E+04 ^c	1.159E+04		1.481E+04	1.481E+04		
Gasoline only (Btu/gal produced)	1.159E+04 ^c	1.017E+04		1.481E+04	1.500E+04		
Gasoline only (Btu/Btu HC produced)	0.103	0.090		0.131	0.133	0.002	
CG only (Btu/gal produced)	1.159E+04 ^c	1.159E+04					
CG only (Btu/Btu HC produced)		0.103					
RFG only (Btu/gal produced)		8.898E+03					
RFG only (Btu/Btu HC produced)		0.079	0.079			0.002	0.81
Total energy in plant fuel burned, natural gas, and electricity to produce HCs							
Total HCs (Btu)	1.682E+12	1.605E+12		4.094E+12	4.139E+12		
Diesel/jet only (Btu) ^b	5.972E+11	5.972E+11		1.735E+12	1.735E+12		
Gasoline only (Btu)	1.085E+12	1.008E+12					
CG only (Btu)		4.902E+11					
RFG only (Btu)		5.177E+11					

TABLE 3.11 (Cont.)

Items	Base Case (No CAAA) ^a (Case Q9W)	55% RFG/Rest CG (MTBE only) (Case Q6W)	RFG-MTBE Only (No case)	62% RFG/Rest CG (MTBE only) (PADD III)	62% RFG/Rest CG (30% EtOH) (PADD III)	Delta for RFG-EtOH Only	RFG-EtOH Only (No case)
Energy in plant fuel burned, natural gas, and electricity to produce HCs							
Total HCs (Btu/gal produced)	1.589E+04 ^c			1.972E+04			
Diesel/jet only (Btu/gal produced) ^b	1.589E+04 ^c	1.589E+04		1.972E+04	1.972E+04		
Gasoline only (Btu/gal produced)	1.589E+04 ^c	1.543E+04		1.972E+04	1.986E+04		
Gasoline only (Btu/Btu HC produced)	0.141	0.137		0.175	0.176	0.001	
CG only (Btu/gal produced)	1.589E+04 ^c	1.589E+04					
CG only (Btu/Btu HC produced)		0.141					
RFG only (Btu/gal produced)		1.502E+04					
RFG only (Btu/Btu HC produced)		0.133	0.133			0.001	0.134

^a CAAA = Clean Air Act Amendments.

^b Energy in plant fuel burned, natural gas, and electricity to produce diesel and jet fuel is held constant across runs.

^c Energy in plant fuel burned, natural gas, and electricity to produce HCs in conventional gasoline is assumed to be the same for gasoline and diesel and jet fuel.

to produce HCs for use in RFG is always lower than the amount required to produce them for CG. There is considerable variation among the RFGs.

3.4.1.3 Other

Some energy and crude oil is required to make the isobutylene for ether produced within the refinery. That energy requirement is implicitly included in this calculation of energy needed to produce HCs for RFG. To avoid doublecounting in the estimate of the energy required to produce ethers for RFG (which includes ether production, both internal and external to the refinery), an estimate of that internal energy use is subtracted in estimates of the energy required to produce ethers.

3.4.2 Energy and Crude Oil Required to Produce MTBE

Table 3.12 presents estimates of the amount of energy and crude oil required to produce MTBE. These estimates are based on a report by Chem Systems, Inc. (1992), which provides estimates of the amount of plant energy required for various MTBE production processes. This analysis assumes that the process that produces MTBE from field butanes is used (see Appendix H). Feedstock for the plant energy and feedstock for the butanes and methanol are estimated on the basis of Chem Systems, Inc. (1992); DeLuchi (1991, 1993); and Delucchi (1993).

This analysis assumes that the energy ratio of natural gas feedstock to methanol produced is 1.5 to 1. The Chem Systems report suggests a lower ratio, but this higher ratio is consistent with sources cited by Delucchi. All the ether plant energy use is assigned to the production of the ether, but the fuel-gas by-products that are also produced are accounted for. Finally, the energy required to produce the field butanes and natural gas used in the system is assumed to be negligible.

As indicated above, some MTBE will be produced within the oil refinery. Table 3.13 presents the final energy requirements to produce MTBE, as a weighting of the energy required to produce MTBE within the refinery (and thus, without MTBE plant energy) and the energy required to produce MTBE in the MTBE plant.

3.4.3 Energy and Crude Oil Required to Produce Ethanol

The energy requirements for corn and ethanol production are derived from DeLuchi (1991, 1993) and Delucchi (1993). These reports contain an extensive analysis of various references that estimate the energy required to produce ethanol. On the basis of these references, Delucchi developed a base-case scenario and alternative scenarios of ethanol production and associated GHG emissions. The base case assumes that corn is used to produce ethanol. Delucchi considers this base case to be representative of current industry average practice. Table 3.14 presents the underlying energy use and crude oil use

TABLE 3.12 MTBE Production from Field Butanes: Capacity of 500,000 Metric Tons per Year

Utility or Feedstock Input ^a	Enthalpy of Steam (Btu/lb steam)	Units per t MTBE	Energy Content (10 ⁶ Btu/unit input)	Energy to Produce Feedstock (10 ⁶ Btu/unit input)	Total Energy input (10 ⁶ Btu/t MTBE)	Total Energy Input (Btu/gal MTBE)	Plant Energy Only (Btu/gal MTBE)	Feedstock for Plant Energy Only (Btu/gal MTBE)	Process Energy for Butanes and Feedstock for MeOH (Btu/gal MTBE)	Total Energy to Produce Feedstock Only (Btu/gal MTBE)	Fuel Type for Production Energy
600-psi steam in tons	1,380	0.67	2.760	0.585	2.24	6,314	5,209	1,105		1,105	Natural gas
Electricity in kWh	NA ^b	40.56	0.003	0.007	0.42	1,170	390	780		780	All fuel sources
Natural gas in 10 ⁶ kcal	NA	0.07	3.968		0.28	782	782	0		0	Natural gas
Field butanes in t	NA	0.7655	42.957		32.88	92,630			0	0	Natural gas
Field butane by-product credit in 10 ⁶ kcal		0.72223	3.968		2.87	8,073					
Field butane process losses ^c						10,375			10,375		Natural gas
Methanol in t	NA	0.3658	18.791	9.396	10.31	29,044			9,681	9,681	Natural gas
Total ^d						121,868	6,381	1,885	20,056	11,566	
Total oil							0	0	0	0	

^a t = metric ton (2,200 lb); ton = short ton (2,000 lb)

^b NA = not applicable.

^c Process losses refer to the consumption of some of the butane feed as fuel rather than as feedstock.

^d Totals are calculated by summing the first four inputs (steam, electricity, natural gas, and butane) and the methanol input and subtracting by-product credits. Process loss is not added because it is already in the total through its inclusion as butane feed (fourth row). Including it in the total would result in double counting.

Sources: Chem Systems, Inc. (1992, Appendix IV, Table A4-40); DeLuchi (1993, Table J.1).

**TABLE 3.13 Weighted Btu Requirements
for Ether Production**

Fuels	Energy Required (Btu required/Btu of ether produced)	
	Energy	Oil
Summer		
For MTBE only in RFG	0.298	0.000
For ETBE only in RFG	0.474	0.029
For MTBE in CG	0.254	0.000
Winter		
For MTBE only in RFG	0.303	0.000
For MTBE in CG	0.284	0.000

**TABLE 3.14 Delucchi's Base-Case
Estimate of Energy and Crude Oil
Required to Produce Ethanol
(Btu/Btu EtOH)**

Energy	
Fertilizer	0.194
Feedstock recovery	0.100
Corn transportation	0.025
Fuel production	<u>0.680</u>
Total without by-product credit	0.999
Total with by-product credit	0.880
Crude oil	
Without by-product credit	0.147
With by-product credit	<u>0.083</u>

assumptions of Delucchi's base case for ethanol production. These assumptions are briefly discussed in Section 4 of this report when they are compared with alternative estimates of the energy and crude oil required to produce ethanol. Tables 3.3 and 3.6 use Delucchi's estimates of the energy and crude oil required to produce ethanol, giving credit for the production of by-products.

3.4.4 Energy and Crude Oil Required to Produce ETBE

The MTBE production process was adapted to develop estimates of the ETBE production process (Table 3.15). This process may slightly understate ETBE process energy,

TABLE 3.15 ETBE Production Adapted from MTBE Production

Utility or Feedstock Input ^a	Enthalpy of Steam (Btu/lb steam)	Units per t ETBE	Energy Content (10 ⁶ Btu/unit input)	Energy to Produce Feedstock (10 ⁶ Btu/unit input)	Total Energy Input (10 ⁶ Btu/t ETBE)	Total Energy Input (Btu/gal ETBE) ^b	Plant Energy Only (Btu/gal ETBE)	Feedstock for Plant Energy Only (Btu/gal ETBE)	Process Energy for Butanes and Feedstock for EtOH (Btu/gal ETBE)	Total Energy to Produce Feedstock Only (Btu/gal ETBE)	Fuel Type for Production Energy
600-psi steam in tons	1,380	0.67	2,760	0.585	2.24	6,386	5,268	1,118		1,118	Natural gas
Electricity in kWh	NA ^c	40.56	0.003	0.007	0.42	1,183	394	789		789	All fuel sources
Natural gas in 10 ⁶ kcal	NA	0.07	3.968		0.28	791	791	0		0	Natural gas
Field butanes in t	NA	0.650	42.036		27.34	77,878				0	Natural gas
Field butane by-product credit in 10 ⁶ kcal		0.614	3.968		2.43	6,936					
Field butane process losses ^d						8,722			8,722		Natural gas
Ethanol in t	NA	0.4512	25.964	22.848	22.02	62,747			29,371	29,371	Some oil
Total ^e						142,050	6,454	1,906	38,093	31,277	
Total oil							0	0	2,770	2,770	

^a t = metric ton (2,200 lb); ton = short ton (2,000 lb).

^b To estimate fossil energy input, the ethanol energy input should be subtracted from the total energy input.

^c NA = not applicable.

^d Process losses refer to the consumption of some butane feed as fuel rather than as feedstock.

^e Totals calculated by summing the first four inputs (steam, electricity, natural gas, and butane) and the methanol input and subtracting by-product credits. Process loss is not added because it is already in the total through its inclusion as butane feed (fourth row). Including it in the total would result in double counting.

Sources: Adapted from Table 3.12; uses Delucchi's ethanol production estimates.

because additional distillation steps are required in ETBE production to achieve the required water removal. The major adaptation was to substitute the energy required to produce ethanol for that required to produce methanol. As was the case for MTBE, this analysis assumes that some ETBE will be produced within the refinery and some outside. The weighted estimate of the energy required to produce the ETBE is also given in Table 3.13.

3.4.5 Energy and Crude Oil Required to Produce Finished Fuels

Columns 8 and 9 of Tables 3.3 and 3.6 provide the final estimates of the amount of energy and crude oil required to produce the various RFGs and CG. Less energy is required to produce RFG with MTBE than to produce RFG with ETBE or ethanol in each season only if the ethanol is new ethanol. If existing ethanol supplies are used, ethanol diverted for use in RFG is replaced by gasoline. Less crude oil is required to produce winter RFG with MTBE than to produce RFG with ethanol, but in the summer, all three RFGs require similar amounts of crude oil. Less energy is required to produce CG than to produce the base RFG in each season. More crude oil is required to produce CG than to produce all the RFGs.

3.5 TOTAL ENERGY, FOSSIL ENERGY, AND CRUDE OIL REQUIRED

Columns 10, 11, and 12 of Table 3.3 estimate the total energy, total fossil energy, and total crude oil requirements of year 2000 RFGs containing 2.1 wt% oxygen, each of which is normalized to the base RFG in terms of delivered energy. Total energy as defined here is the sum of the energy content of the final fuel and energy consumed in production processes. It does not include the full energy cycle (e.g., some crude-oil field production energy and energy used in fuel transportation are not included). Table 3.16 converts these estimates into relative estimates, with the base being summer RFG with MTBE. The likely alternative to winter RFG with ethanol is winter RFG with MTBE, not the base RFG.

On a per-gallon and seasonal basis, the total energy requirement is between 0.6% and 1.3% lower for RFG with ethanol (as ethanol or ETBE) than for RFG with MTBE, if the RFG with ethanol is made with existing ethanol (ethanol diverted from existing sources). The total energy requirement is between 1.3% and 1.8% higher if the RFG with ethanol is made with new ethanol. In all cases, RFG requires more energy than CG.

The fossil energy requirement is lower for all the renewable-oxygenated RFGs than for MTBE-oxygenated RFGs — up to 2.2% lower on a per-gallon basis. In some cases, CG requires less fossil energy than RFG.

The amount of crude oil use associated with using RFGs with ETBE and ethanol is almost always higher than that estimated for using RFG with MTBE — up to 11% higher when winter RFGs are compared. Only RFG with ETBE made from new ethanol uses less crude oil than RFG with MTBE. In all cases, RFG requires less crude oil than CG, but the use of existing ethanol in winter RFG greatly reduces the crude oil saving relative to CG.

TABLE 3.16 Energy Content and CO₂-Equivalent Emissions of Summer and Winter RFGs Based on Delucchi's Estimate of Energy and Crude Oil Required to Produce Ethanol: Values Relative to Summer RFG with MTBE

Fuel Type ^a	Total Energy Required to Deliver RFG	Total Fossil Energy Required to Deliver RFG	Total Crude Oil Required to Deliver RFG	CO ₂ -Equivalent Emissions
<i>Summer</i>				
RFG with MTBE at 2.1%	1.000	1.000	1.000	1.000
RFG with ETBE at 2.1% (new EtOH)	1.018	0.983	0.980	1.007
RFG with ETBE at 2.1% (existing EtOH)	0.992	0.992	1.022	0.996
CG in PADD II	0.987	0.987	1.119	0.998
<i>Winter</i>				
RFG with MTBE at 2.1%	0.981	0.981	0.983	0.962
RFG with EtOH at 2.1% (new EtOH)	0.995	0.959	1.051	0.977
RFG with EtOH at 2.1% (existing EtOH)	0.969	0.969	1.092	0.964
RFG with MTBE at 2.7%	0.986	0.986	0.952	0.962
RFG with EtOH at 2.7% (new EtOH)	1.003	0.956	1.039	0.980
RFG with EtOH at 2.7% (existing EtOH)	0.969	0.969	1.092	0.965
CG in PADD II	0.976	0.976	1.099	0.975

^a 2.1% and 2.7% refer to the oxygen content in weight percent. New EtOH = incrementally produced ethanol as opposed to ethanol diverted from existing markets. Existing EtOH = ethanol diverted from existing markets.

Table 3.6 presents the total energy, fossil energy, and crude oil requirements of winter RFG containing 2.7 wt% oxygen. Table 3.16 converts the results of Table 3.6 into relative estimates. The relative results (versus the base-case RFG) are very similar to those for the RFGs containing 2.1 wt% oxygen.

An increase from 2.1 to 2.7 wt% in the oxygen content of RFG containing existing ethanol causes no significant change in its total energy, fossil energy, or crude oil requirements. Total energy requirements increase for the RFGs with MTBE and new ethanol over those of RFGs containing 2.1 wt% oxygen. Fossil energy requirements increase with greater use of MTBE and decline with greater use of new ethanol. Crude oil use decreases for both RFG with MTBE and RFG with new ethanol.

3.6 GREENHOUSE GAS EMISSIONS OF REFORMULATED GASOLINE

3.6.1 Factors

Table 3.17 presents estimates of the GHG, or CO₂-equivalent, emissions of the various components of RFG. These estimates are derived from Delucchi's GHG model and

TABLE 3.17 CO₂-Equivalent Emissions of RFG Components

Fuel	CO ₂ -Equivalent Emissions (g/Btu of fuel)
MTBE	0.10133
ETBE	0.11152
EtOH	0.13390
Summer HCs for CG	0.10554
Winter HCs for CG	0.10304
Summer HCs for RFG with MTBE	0.10614
Winter HCs for RFG with MTBE	0.10165
Summer HCs for RFG with ETBE	0.10574
Winter HCs for RFG with EtOH	0.10186

assume his base case for ethanol production. Alternative estimates of the GHG emissions associated with ethanol production are provided in Section 4.

Table 3.17 is based on Table G.1 in Appendix G, which is Delucchi's base case for alternative fuels as of August 1993. As stated previously, the GHG emissions associated with vehicle materials and assembly are not considered here. The estimates in grams per mile (g/mi) provided in Table G.1 can be converted into grams per Btu (g/Btu). With these two modifications, the GHG emissions of ethanol (and methanol) can be directly estimated from Table G.1. Delucchi's model was run several times to estimate the GHG emissions associated with MTBE only (i.e., the difference in emissions between CG with MTBE and CG without MTBE was used to derive the GHG emissions of MTBE). Once the GHG emissions associated with MTBE were estimated, the GHG emissions associated with ETBE were estimated by substituting data on GHG emissions from ethanol production for data on GHG emissions from methanol production. The fact that ethanol makes up a greater volume percent of ETBE than methanol does of MTBE was factored into the ETBE GHG emission calculation.

Delucchi provided estimates of the GHG emissions associated with the use of CG containing MTBE. This analysis assumes that this CG is a summer fuel. The GHG emissions associated with the HCs for this summer CG were disaggregated from those for MTBE. For HCs used in RFGs, the GHG emissions were based on the energy required to produce these HCs relative to the energy required to produce the HCs for CG. (The amount of energy required to produce the various HCs is presented in Table 3.10.)

3.6.2 Results

Tables 3.3 and 3.6 apply the factors presented in Table 3.17 to the energy content of the components of the various RFGs to derive total GHG emissions for the RFGs. Table 3.16 converts these estimates into relative estimates, with the base case being summer

RFG with MTBE. Winter RFGs generate fewer CO₂-equivalent emissions than summer RFGs when both are oxygenated with MTBE. Winter RFG with ethanol generates fewer emissions than summer RFG with ETBE as well. If new ethanol is used to supply ether feedstock (summer) or ethanol for oxygenate blending (winter), the resulting RFGs emit more GHGs (about 1% more in each case) than are produced if existing ethanol use is diverted to supply this ethanol. Similarly, use of new ethanol leads to more GHG emissions than use of MTBE. In some instances, the GHG emissions associated with CG are fewer than those associated with RFG.

3.7 MOST LIKELY RESULTS

The programwide impacts of using the RFGs analyzed in this section are reported in Section 5. The estimates presented in this section indicate that in general, a year-round program in which only RFG containing MTBE is used will use more total energy and fossil energy than would a program in which only CG is used. However, use of RFG with MTBE only will reduce crude oil requirements and perhaps reduce GHG emissions. All of these changes are likely to be on an order of a few percentage points or less. (This comparison assumes the use of summer fuels for 5.5 months of the year and winter fuels for 6.5 months.)

With respect to the ROS mandate, relatively little, if any, ETBE is likely to be used in the near term (subject to variations in the methanol/ethanol price relationship). RFG with ethanol will be used, and in the near term, much of the ethanol will be diverted from existing sources. Therefore, relative to the all-MTBE case, the ROS in the near term should reduce total energy and fossil energy use, increase crude oil use, and have virtually no effect on GHG emissions.

In the long term, both ETBE and ethanol will probably be used, and ethanol production capacity will increase so that more new ethanol will be used. The implications of these trends are explored more fully in Section 5. Use of RFG containing ETBE from new ethanol will likely increase total energy use, reduce fossil energy and crude oil use, and increase GHG emissions relative to use of RFG containing MTBE. These changes are all within a few percent or less.

4 ALTERNATIVE ESTIMATES OF THE IMPACTS OF USING REFORMULATED GASOLINE WITH ETHANOL ON ENERGY USE AND GREENHOUSE GAS EMISSIONS

4.1 INTRODUCTION

There is substantial uncertainty about the amount of energy that is required to produce ethanol from corn and the GHG emissions that are associated with the production and use of ethanol. The analysis of energy requirements and GHG emissions associated with using various oxygenates in RFG presented in Section 3 was based on Delucchi's base-case estimates of the energy and crude oil required to produce ethanol (DeLuchi 1991, 1993; Delucchi 1993b). This section analyzes the effects on the basis of alternative assumptions about ethanol's energy production requirements. Although Delucchi developed a number of alternative scenarios on the amount of energy and crude oil required to produce corn-based ethanol, this section uses two other references: estimates developed by the USDA (Conway et al. 1994) and estimates developed by Ho of Amoco Oil Company (Ho 1989). The USDA's estimates are approximately 25% lower than Delucchi's base-case estimates of the energy required to produce ethanol from corn, and Ho's are about 22% higher.

To analyze the effects of these different assumptions and estimates, the USDA and Ho estimates were input into Delucchi's model to generate alternative estimates of the GHG emissions associated with the use of ethanol. These alternative estimates of the energy and crude oil use and GHG emissions associated with the use of ethanol in RFG then served as input to the ANL model of energy requirements and GHG emissions associated with RFG. The effect of these alternative ethanol estimates on the energy and crude oil use and GHG emissions associated with the use of various oxygenates in RFG were then evaluated.

4.2 DELUCCHI'S ESTIMATES OF ENERGY AND CRUDE OIL REQUIRED TO PRODUCE ETHANOL

The RFG analysis presented in Section 3 is based on Delucchi's estimates of the amount of energy and crude oil required to produce ethanol and the GHG emissions associated with such production. (These estimates are thoroughly explained in DeLuchi 1991 and 1993 and Delucchi 1993). The derivation of these estimates is not repeated here except to highlight where they differ from the USDA and Ho estimates.

Table 4.1 presents Delucchi's base-case estimates of the amount of energy and crude oil required to produce ethanol, with and without credit given for by-products. These estimates are presented in Delucchi's reports and in the August 1993 version of his spreadsheet model. In his model, Delucchi characterizes the process energy consumed in several stages of fuel production: fertilizer manufacture, feedstock recovery, feedstock transportation, fuel production, fuel distribution, and liquid loss. The latter two stages are not included here in this analysis of the energy and crude oil required to produce ethanol.

TABLE 4.1 Alternative Estimates of Energy and Crude Oil Required to Produce Ethanol

Reference and Fuel Production Stage	Energy Required with No By-Product Credits (Btu/Btu EtOH)	Energy Required with By-Product Credits (Btu/Btu EtOH)	Crude Oil Share (%)	Crude Oil Required with By- Product Credits (Btu/Btu EtOH)
Delucchi				
Fertilizer manu- facture and transport	0.1936	0.1936	28	
Feedstock recovery	0.1000	0.0050	67	
Corn transportation	0.0255	0.0255	100	
Ethanol production	0.6800	0.6560		
Coal	0.5300	0.5060	0	
Electricity	0.05 ^a	0.05 ^a	0	
Total	0.999	0.880		0.083
USDA				
Fertilizer manu- facture and transport	0.1749	0.1749	9.5	
Feedstock recovery	0.0863	0.0233	63	
Corn transportation	0.0098	0.0098	100	
Ethanol production	0.4770	0.4613		
Coal	0.4770	0.4613	0	
Electricity	0	0	0	
Total	0.748	0.669		0.041
Ho				
Fertilizer manu- facture and transport	0.2105	0.2105	0	
Feedstock recovery	0.2237	0.1317	100	
Corn transportation	0.0255	0.0255	100	
Ethanol production	0.7480	0.7090		
Coal	0.5920	0.5530	0	
Electricity	0.052 ^a	0.052 ^a	0	
Total	1.208	1.077		0.1572

^a At 3,413 Btu/kWh.

Although Delucchi's report provides a range of estimates for the coal required in the ethanol plant, this analysis uses the point estimate that he used for his base case. The crude oil share estimates include fuel crude oil, diesel fuel, and gasoline used in the various stages of ethanol production.

4.3 USDA ESTIMATES OF ENERGY AND CRUDE OIL REQUIRED TO PRODUCE ETHANOL

The USDA's estimates of the total energy requirements for ethanol production from corn were submitted as part of its comments on the EPA's ROS proposal. Delucchi compared the USDA estimates with his base-case estimates and provided the comparison to DOE in March 1994. The key differences are as follows:

1. The USDA's fertilizer requirement estimates are approximately 25% lower than Delucchi's: 29,000 versus 38,300 Btu/bushel. Delucchi believes the USDA estimate is probably a reasonable estimate of best practice, while his estimate is of average practice. His fertilizer estimate was lower than those in all but one of the reports he analyzed. (See Appendix G, Table G.2, for Delucchi's summary of various reports' estimates of the energy required to produce ethanol.)
2. The USDA estimates that farm energy requirements in the form of diesel fuel, gasoline, liquefied petroleum gas (LPG), and power are 19,000 Btu per bushel; Delucchi's estimates are higher, at 22,000 Btu per bushel. Again, Delucchi believes that the USDA's estimates may be reasonable for best practice, while his are reasonable for average practice.
3. The USDA's estimate for seeds and chemicals required in farming is about 1,000 Btu per bushel below Delucchi's (5,900 versus 7,000 Btu per bushel). Still, both estimates represent 20% of their respective estimates of fertilizer requirements.
4. The USDA estimates approximately 800 Btu/gal of energy is used for corn transport; Delucchi estimates approximately 2,200 Btu/gal.
5. The USDA estimates that the energy required in ethanol plants is 47,400 Btu/gal for the dry milling process and 36,300 Btu/gal for the wet milling process. These estimates convert to 0.565 Btu of coal per Btu of ethanol and 0.433 Btu-coal/Btu-ethanol, respectively. The USDA assumes that electricity can be cogenerated from the heat supplied by the coal. Delucchi's base case uses 0.53 Btu-coal/Btu-ethanol, with an additional 0.05 Btu-electricity/Btu-ethanol. Accounting for generation losses, Delucchi's base case is approximately 0.68 Btu total energy/Btu

ethanol. Delucchi believes that the USDA's estimates are reasonable state-of-the-art estimates.

6. The USDA assumes that wet milling plants represent approximately two-thirds of all ethanol plants. Most of Delucchi's estimates were based on the assumption that ethanol plants are wet, not dry, milling plants.
7. The USDA does not give any by-product credits, although it does deduct the 7,000 Btu/gal that is used to dry by-products in the wet milling process. By-product credits in Delucchi's base case total approximately 12,000 Btu/gal. These credits include credits for production of (1) ammonium sulfate from the flue gases of an ethanol facility (displaces fertilizer); (2) distillers dried grains and solubles (DDGS) produced by the ethanol-production process (displace soybean meal); and (3) fusel oil, a mixture of higher alcohols and higher esters, which is also produced by the ethanol production process (displaces the coal process fuel).

On the basis of this analysis of key differences, USDA estimates were put into Delucchi's model. Most of the inputs are straightforward. The USDA's estimates of the amount of crude oil used in all the stages of ethanol production were evaluated and found to be different from Delucchi's estimates; therefore, the USDA's were used. The USDA's crude oil share estimates are presented in Table 4.1.

This analysis also put by-product credits into the USDA estimates. Delucchi's estimates were used as a base, but credits for DDGS and fusel oil production were assumed to apply only to the wet milling plants. In addition, Delucchi indicated that the ammonium sulfate credit that he used should be reduced (by about 25%) because best-practice plants, which the USDA has apparently assumed, will use low-sulfur coal and use it relatively efficiently. (This credit is actually subtracted directly from the fertilizer requirements before energy required to produce fertilizer is estimated in the Delucchi model.)

The results of all the above changes to Delucchi's model result in the USDA estimates presented in Table 4.1. The USDA's estimates of the energy required to produce ethanol are approximately 25% lower than Delucchi's, and its crude oil requirements are 50% lower.

4.4 HO'S ESTIMATES OF ENERGY AND CRUDE OIL REQUIRED TO PRODUCE ETHANOL

Ho's estimates were included in those surveyed by Delucchi, Ho's estimates are among those presented in Appendix G, Table G.2. This analysis used Delucchi's summary of Ho's estimates, supplementing it with additional detail from the original Ho paper to input its energy and crude oil use estimates into Delucchi's model.

Specifically, estimates of the crude oil share of each stage of the ethanol production process and estimates of by-product credit by stage were drawn from Ho's paper. The estimates of crude oil share are presented in Table 4.1. Ho provides no credit for ammonium sulfate production, which may explain in part why his estimate of the energy required for fertilizer manufacture is higher than Delucchi's. Ho gives credit for DDGS and fusel crude oil production. Ho's credit for DDGS is virtually the same as Delucchi's, about 8,000 Btu/gal higher heating value (HHV). His credit for fusel oil production is higher (3,300 versus 2,000 Btu/gal HHV).

Other than the above information, Ho does not provide sufficient detail to allow a determination of the key differences between his assumptions and Delucchi's. They are simply input here as stated in his paper. Because Ho did not estimate the energy used to transport corn, Delucchi's estimate is used to complete Ho's estimates. The above changes to Delucchi's model result in the Ho estimates presented in Table 4.1. Ho's estimate of the energy required to produce ethanol is approximately 22% higher than Delucchi's, and his estimate of crude oil requirements is 90% higher.

4.5 GREENHOUSE GAS EMISSIONS ASSOCIATED WITH THE USE OF ETHANOL

The USDA and Ho estimates of energy and crude oil use (with credit given for by-products) were input to Delucchi's GHG emission model to estimate the implications of the two sets of estimates on GHG emissions. Results are presented in Table 4.2. They represent the full fuel cycle for these fuels. The USDA's estimates of GHG emissions from using ethanol are 20% lower than Delucchi's; Ho's estimates are 10% higher than Delucchi's.

4.6 TOTAL ENERGY AND CRUDE OIL REQUIREMENTS AND GREENHOUSE GAS EMISSIONS OF REFORMULATED GASOLINE BASED ON ALTERNATIVE ESTIMATES OF ENERGY AND CRUDE OIL REQUIRED TO PRODUCE ETHANOL

The USDA and Ho estimates of the energy required to produce ethanol (with credit given for by-products) and the GHG emission estimates derived from these energy production estimates were input to the ANL spreadsheet model. This model calculates the total energy, fossil energy, and crude oil requirements and GHG emissions of various RFGs. The resulting tables are presented in Appendix H; they are comparable to Tables 3.3 and 3.6, which use Delucchi's ethanol estimates. A summary of the estimates is presented in Table 4.3. Table 4.4 converts the estimates into relative per-gallon estimates, with the base case being summer RFG containing MTBE.

TABLE 4.2 Various Estimates of CO₂-Equivalent Emissions of Ethanol and ETBE

Fuel	Emissions per Study (g/Btu of fuel)		
	Delucchi	USDA	Ho
ETBE	0.11152	0.10093	0.11695
Ethanol	0.13390	0.10899	0.14667

TABLE 4.3 Energy Content and CO₂-Equivalent Emissions of Summer and Winter RFGs Based on Alternative Estimates of Energy and Crude Oil Required to Produce Ethanol: Absolute Values

Fuel Type ^a	Total Energy Required to Deliver RFG (Btu)	Total Fossil Energy Required to Deliver RFG (Btu)	Total Crude Oil Required to Deliver RFG (Btu)	CO ₂ - Equivalent Emissions (G)
<i>Summer</i>				
RFG with MTBE at 2.1%	131,308	131,308	110,988	11,844
RFG with ETBE at 2.1% (new EtOH)				
Delucchi	133,687	129,012	108,800	11,926
USDA	132,744	128,069	108,612	11,789
Ho	134,568	129,892	109,131	11,997
RFG with ETBE at 2.1% (existing EtOH)				
Delucchi	130,297	130,297	113,403	11,794
USDA	130,340	130,340	113,412	11,773
Ho	130,256	130,256	113,388	11,804
CG in PADD II	129,611	129,611	124,229	11,821
<i>Winter</i>				
RFG with MTBE at 2.1%	128,874	128,874	109,104	11,389
RFG with EtOH at 2.1% (new EtOH)				
Delucchi	130,680	125,940	116,621	11,568
USDA	129,680	124,940	116,422	11,450
Ho	131,614	126,874	116,972	11,629
RFG with EtOH at 2.1% (existing EtOH)				
Delucchi	127,178	127,178	121,218	11,422
USDA	127,178	127,178	121,218	11,422
Ho	127,178	127,178	121,218	11,422
RFG with MTBE at 2.7%	129,418	129,418	105,639	11,388
RFG with EtOH at 2.7% (new EtOH)				
Delucchi	131,694	125,595	115,333	11,612
USDA	130,407	124,308	115,077	11,460
Ho	132,895	126,796	115,785	11,690
RFG with EtOH at 2.7% (existing EtOH)				
Delucchi	127,186	127,186	121,248	11,423
USDA	127,186	127,186	121,248	11,423
Ho	127,186	127,186	121,248	11,423
CG in PADD II	128,141	128,141	121,952	11,545

^a 2.1% and 2.7% refer to oxygen content in weight percent. New EtOH = incrementally produced ethanol as opposed to ethanol diverted from existing markets. Existing EtOH = ethanol derived from existing markets.

TABLE 4.4 Energy Content and CO₂-Equivalent Emissions of Summer and Winter RFGs Based on Alternative Estimates of Energy and Crude Oil Required to Produce Ethanol: Values Relative to Summer RFG with MTBE

Fuel Type ^a	Total Energy Required to Deliver RFG	Total Fossil Energy Required to Deliver RFG	Total Crude Oil Required to Deliver RFG	CO ₂ - Equivalent Emissions
<i>Summer</i>				
RFG with MTBE at 2.1%	1.000	1.000	1.000	1.000
RFG with ETBE at 2.1% (new EtOH)				
Delucchi	1.018	0.983	0.980	1.007
USDA	1.011	0.975	0.979	0.995
Ho	1.025	0.989	0.983	1.013
RFG with ETBE at 2.1% (existing EtOH)				
Delucchi	0.992	0.992	1.022	0.996
USDA	0.993	0.993	1.022	0.994
Ho	0.992	0.992	1.022	0.997
CG in PADD II	0.987	0.987	1.119	0.998
<i>Winter</i>				
RFG with MTBE at 2.1%	0.981	0.981	0.983	0.962
RFG with EtOH at 2.1% (new EtOH)				
Delucchi	0.995	0.959	1.051	0.977
USDA	0.988	0.952	1.049	0.967
Ho	1.002	0.966	1.054	0.982
RFG with EtOH at 2.1% (existing EtOH)				
Delucchi	0.969	0.969	1.092	0.964
USDA	0.969	0.969	1.092	0.964
Ho	0.969	0.969	1.092	0.964
RFG with MTBE at 2.7%	0.986	0.986	0.952	0.961
RFG with EtOH at 2.7% (new EtOH)				
Delucchi	1.003	0.956	1.039	0.980
USDA	0.993	0.947	1.037	0.968
Ho	1.012	0.966	1.043	0.987
RFG with EtOH at 2.7% (existing EtOH)				
Delucchi	0.969	0.969	1.092	0.964
USDA	0.969	0.969	1.092	0.964
Ho	0.969	0.969	1.092	0.964
CG in PADD II	0.976	0.976	1.099	0.975

^a 2.1% and 2.7% refer to oxygen content in weight percent. New EtOH = incrementally produced ethanol as opposed to ethanol diverted from existing markets. Existing EtOH = ethanol derived from existing markets.

Table 4.3 indicates that using the alternative estimates of energy and crude oil to produce ethanol results in very small changes (relative to Delucchi's estimates) in total RFG energy and crude oil use and GHG emissions. For example (on the basis of only the new ethanol estimates), the USDA estimate of the amount of energy required to produce ethanol, which is 25% lower than Delucchi's, translates into a reduction of 0.7% to 1% in the total energy or fossil energy requirements of a gallon of RFG containing ethanol or ETBE. The 50% reduction from Delucchi's estimate of the amount of crude oil used in ethanol production translates into a 0.2% reduction in the total crude oil requirements of a gallon of RFG containing ethanol or ETBE. The biggest change is in the CO₂ estimates; the USDA's estimates lead to a 1% to 1.3% reduction, relative to Delucchi's estimates, in the CO₂ emissions associated with RFG containing ethanol or ETBE.

Table 4.4 indicates that use of the USDA and Ho estimates results in only one change in the direction of relative RFG effects. In that one case, the USDA estimates indicate a 0.5% decrease in CO₂ emissions as a result of using summer RFG with ETBE (new ethanol) relative to summer RFG with MTBE, while Delucchi estimates indicate a 0.7% increase.

5 PROGRAMWIDE ENERGY USE AND GREENHOUSE GAS EMISSION EFFECTS OF THE RENEWABLE OXYGENATE STANDARD

In Section 5, the results of Sections 2, 3, and 4 of this report are used to determine the national energy and GHG consequences of the ROS. The programwide impacts of fuel mixes that comply with the ROS are compared with impacts of RFG oxygenated only with MTBE. CG is also compared with RFG. Likely near-term and long-term operation of the program is evaluated on the basis of the assumption that 30% of the RFG will be oxygenated (i.e., the phase-in period is not evaluated).

Required volumes of each type of RFG were derived from the demand estimates in Section 2. Table 5.1 presents these volumes in base RFG-equivalent units.³⁰ In the near-term analysis, ethanol is assumed to be the only renewable oxygenate available and its use is assumed to be restricted to the winter.³¹ In the long-term analysis, it is assumed that ETBE will also be available and that oxygenation with renewables will occur year-round, with ethanol being used in the winter and ETBE being used in the summer. For comparative purposes, total RFG demand is held constant for the near-term and long-term cases.

The program-level impacts are estimated by multiplying the volume of each type of fuel (taken from Table 5.1) by the corresponding per-gallon energy consumption or GHG emission factors (taken from Table 3.3 [non-OG RFG] or Table 3.6 [OPRG] for the Delucchi base case or taken from the analogous tables in Appendix H for USDA or Ho alternative estimates of energy required to produce ethanol). The result of this calculation is total energy use in Btu/year (or CO₂-equivalent/year) for the program weighted by fuel type. These obsolete results and relative results are reported in Tables 5.2 and 5.3 for the near-term and Tables 5.4 and 5.5 for the long-term.

For example, the following equation calculates the total crude oil requirement of base RFG,³² weighted by fuel type, on the basis of Tables 5.1, 3.3, and 3.6: [(16.1e9 gal summer RFG/yr) (110,988 Btu/gal)] + [(10.6e9 gal winter RFG/yr) (109,104 Btu/gal)] + [(8.5e9 gal winter RFG-OG/year) (105,639 Btu/gal)] = 3.84e15 Btu/year of crude oil consumed.

Differences between results calculated with the values in the tables and those reported in Tables 5.2 and 5.4 are due to rounding in the tables.

Table 5.2 summarizes the near-term, programwide impacts (on annual total energy, fossil energy, and crude oil requirements and on GHG emission) from using (1) RFG with

³⁰ Base RFG is summer, MTBE-oxygenated RFG containing 2.1 wt% oxygen.

³¹ Recall that ethanol may be used during the summer under the ROS, but it does not qualify for renewable credit.

³² This amount will be the same for Delucchi, USDA, and Ho, since no ethanol is involved.

TABLE 5.1 Volumes of Fuels Used for Programwide Impact Analysis^a

Item	Base-RFG-Equivalent (10 ⁹ gal) ^b
Base RFG used	
Summer RFG with MTBE	16.1
Winter Non-OG RFG with MTBE	10.6
Winter OPRG with MTBE	8.5
Renewables used in winter only	
Summer RFG with MTBE	16.1
Winter Non-OG RFG with MTBE	4.7
Winter Non-OG RFG with EtOH	5.9
Winter OPRG with MTBE	3.8
Winter OPRG with EtOH	4.7
Renewables used year-round	
Summer RFG with MTBE	11.3
Summer RFG with ETBE	4.8
Winter Non-OG RFG with MTBE	7.4
Winter Non-OG RFG with EtOH	3.2
Winter OPRG with MTBE	5.9
Winter OPRG with EtOH	2.5
CG used in RFG areas	
Summer	16.1
Winter	19.1

^a Volumes are consistent with Section 2 demand calculations. Volumes of RFG presented in this table have been rounded, resulting in an apparent difference in volumes for various scenarios presented. Unrounded volumes have been used to calculate the results presented in Tables 5.2 through 5.5.

^b Base RFG is summer RFG with MTBE containing 2.1 wt% oxygen.

TABLE 5.2 Programwide Impacts of the ROS in the Near Term: Absolute Values

Item	Total Energy Requirement (Btu/yr)	Total Fossil Energy Requirement (Btu/yr)	Total Crude Oil Requirement (Btu/yr)	CO ₂ -Equivalent Emissions (g/yr)
Base RFG used	4.58E+15	4.58E+15	3.84E+15	4.08E+14
Renewables used in winter only				
Delucchi	4.58E+15	4.55E+15	3.96E+15	4.09E+14
USDA	4.57E+15	4.55E+15	3.96E+15	4.09E+14
Ho	4.58E+15	4.56E+15	3.96E+15	4.09E+14
CG used in RFG areas	4.54E+15	4.54E+15	4.33E+15	4.11E+14

TABLE 5.3 Programwide Impacts of the ROS in the Near Term: Values Relative to Base RFG

Item	Total Energy Requirement	Total Fossil Energy Requirement	Total Crude Oil Requirement	CO ₂ -Equivalent Emissions
Base RFG used	1	1	1	1
Renewables used in winter only				
Delucchi	0.999	0.994	1.031	1.002
USDA	0.997	0.992	1.031	1.000
Ho	0.999	0.994	1.031	1.003
CG used in RFG areas	0.990	0.990	1.127	1.007

TABLE 5.4 Programwide Impacts of the ROS in the Long Term: Absolute Values

Item	Total Energy Requirement (Btu/yr)	Total Fossil Energy Requirement (Btu/yr)	Total Crude Oil Requirement (Btu/yr)	CO ₂ -Equivalent Emissions (g/yr)
Base RFG used	4.58E+15	4.58E+15	3.84E+15	4.08E+14
Renewables used in winter only				
Weighted				
Delucchi	4.58E+15	4.56E+15	3.91E+15	4.09E+14
USDA	4.57E+15	4.55E+15	3.91E+15	4.08E+14
Ho	4.58E+15	4.56E+15	3.91E+15	4.09E+14
100% new				
Delucchi	4.60E+15	4.55E+15	3.88E+15	4.10E+14
USDA	4.59E+15	4.54E+15	3.87E+15	4.08E+14
Ho	4.61E+15	4.56E+15	3.88E+15	4.10E+14
CG used in RFG areas	4.54E+15	4.54E+15	4.33E+15	4.11E+14

TABLE 5.5 Programwide Impacts of the ROS in the Long Term: Values Relative to Base RFG

Item	Total Energy Requirement	Total Fossil Energy Requirement	Total Crude Oil Requirement	CO ₂ - Equivalent Emissions
Base RFG used	1	1	1	1
Renewables used in winter only				
Weighted				
Delucchi	0.999	0.995	1.017	1.001
USDA	0.998	0.993	1.017	0.999
Ho	1.000	0.995	1.017	1.001
100% new				
Delucchi	1.004	0.993	1.009	1.003
USDA	1.002	0.990	1.008	0.999
Ho	1.006	0.995	1.010	1.005
CG used in RFG areas	0.990	0.990	1.127	1.007

MTBE only (base RFG), (2) RFG that satisfies the ROS requirement (containing 30% renewable oxygenates), and (3) CG. Table 5.3 presents data on the effects of the ROS requirement on using RFG containing MTBE only. Meeting the ROS is estimated to lower fossil energy use by 0.6-0.8% from that of the base case, but crude oil use is 3.1% higher and GHG emissions are either equal or up to 0.3% higher.

The near-term results presented for the fuel mix have been calculated by weighting new and existing ethanol. As defined in Sections 3 and 4, "existing ethanol" is ethanol diverted from existing markets. "New ethanol" is produced incrementally (i.e., additional) to that produced for existing markets. The analysis estimates that about 60% of the ethanol used to satisfy the ROS in the near term will be new. The source of the new ethanol will be current excess capacity plus additional winter capacity projected by EPA for 1996.

Tables 5.4 and 5.5 present the same information as Tables 5.2 and 5.3, but for the long-term analysis. Because the use of existing and new ethanol to satisfy ROS requirements is likely to be different in the long term, two alternatives are presented. Weighted results are based on the same weighting of new and existing ethanol that is used for the near-term analysis. Ethanol defined as "100% new" is based on the assumption that all ethanol used in RFG is new. These examples are designed to show what the weighting might be; that they are not projections. The weighting assumptions are applied to ethanol blended directly during the winter and ethanol used to make ETBE for summer use.

In the long-term, on the basis of using "weighted" sources of ethanol, implementation of the ROS should reduce fossil energy use by 0.5% to 0.7%, increase crude oil use by 1.6%, and either reduce GHG emissions by 0.1% or raise them 0.2% at most. Use of 100%-new ethanol should decrease fossil energy use by about 0.5% to 1.0%, increase crude oil use by 0.8% to 1.0%, and either reduce GHG emissions by 0.1% or raise them 0.5% at most.

Tables 5.3 and 5.5 suggest that meeting the ROS will have the following outcomes relative to using RFG with MTBE only, both for the near and long term:

1. The ROS will result in a small decrease in fossil energy use that is no greater than 1%.
2. The ROS will result in an increase in crude oil use of about 1-3%.
3. The ROS will have essentially no effect on GHG emissions as long as corn-based ethanol is used. Large uncertainties are associated with estimating the GHG emissions of various fuels. This analysis generates differences among estimates on the order of about 0.5% or less. Given the uncertainties associated with GHG estimates, the conclusion is that the RFGs containing various oxygenates are essentially no different in terms of their GHG emissions.
4. Using alternative estimates (e.g., USDA and Ho) of the amount of energy and crude oil required to produce ethanol results in only very small (at most 0.4%) programwide impacts.

The tables also indicate that using RFG rather than CG will (1) slightly increase fossil energy use, (2) substantially reduce crude oil use, and (3) probably slightly reduce GHG emissions. Because only a small fraction of RFG is oxygenate, differences between fuels that hinge on differences between oxygenates (e.g., the crude oil content of ethanol versus that of MTBE) are much smaller than the differences between oxygenates.

6 CONCLUSIONS

6.1 ETHANOL DEMAND

The ROS is likely to lead to some displacement of ethanol from existing markets, particularly in the near term. The fact that some areas that had opted into the RFG program have recently opted out may have decreased this potential somewhat, but not completely.

- During the first year, under the 15% renewable requirement and at current ethanol production capacity, about 15% of the ethanol would have to be diverted to satisfy the ROS over a full winter season. For the front-loaded case, 83% of the ethanol would have to be diverted.
- In the near term, under the 30% renewable requirement and at higher ethanol production capacity, 25% of the ethanol would have to be diverted to satisfy the ROS over a full winter season. For the front-loaded case, 100% of the ethanol would have to be diverted for use in RFG.
- In the long term, if ethanol production is at 1996 levels, 34% of the ethanol would have to be diverted to meet winter-only renewable use. This result suggests that ethanol capacity (or inventory) is likely to expand beyond near-term levels.
- In all cases, at current stock levels of ethanol, maximum inventory drawdown would reduce but not eliminate the diversion of ethanol during the winter.
- Year-round oxygenation of renewables would eliminate the need for diverting ethanol.
- In all cases, more ethanol would need to be transported to RFG areas, even with maximum use of credit trading. Further study of the ethanol logistics system is warranted to determine the importance of such increases.

6.2 ENERGY USE AND GREENHOUSE GAS EMISSIONS OF REFORMULATED GASOLINE

If corn-based ethanol is used, the ROS will have a small impact on energy use and GHG emissions associated with RFG production and use.

- Relative to RFG oxygenated with MTBE only, RFG oxygenated with ethanol (both directly and with ethanol in ETBE) can be expected to

slightly reduce fossil energy use, increase crude oil use, and have essentially no effect on GHG emissions.

- If the ROS is implemented, the increase in crude oil requirements would be greatest if ethanol were the only renewable oxygenate. The programwide impact would be approximately 3%.
- The effects of the ROS at the programwide level on fossil energy requirements and GHG emissions would all be very small: 1% or less. Given the uncertainty associated with estimating GHG emissions, the conclusion is that the ROS would have essentially no effect on GHG emissions.

In this analysis, using alternative estimates of the amount of energy required to produce ethanol from corn made little difference on the effects of the ROS. First of all, ethanol represents a small portion of a gallon of renewable RFG. Moreover, any differences between estimates of the energy required to produce ethanol are further diminished over a programwide level, since only 30% of the RFG must be oxygenated with renewables under the ROS.

- When the two most divergent estimates of the energy required to produce ethanol were used, resultant estimates of fossil energy and crude oil requirements and GHG emissions were found to differ by only 1-2% on a per-gallon basis.
- On a programwide level, the differences in results for the alternative ethanol estimates are 0.5% or less for all categories for use of both weighted and 100%-new ethanol. Differences of this magnitude should be considered insignificant.

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APPENDIX A:
CHANGES RELATIVE TO EARLIER ARGONNE ANALYSES
OF REFORMULATED GASOLINE AND THE RENEWABLE
OXYGENATE STANDARD

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APPENDIX A:

**CHANGES RELATIVE TO EARLIER ARGONNE ANALYSES
OF REFORMULATED GASOLINE AND THE RENEWABLE
OXYGENATE STANDARD**

Many of the calculations presented in this report were used in earlier versions of the analysis presented here. However, substantial revisions were made in several of the newer versions. These changes were made to address the comments of peer reviewers, correct calculational errors, and update reference data. In this version of the analysis, total gasoline-equivalent demand for transportation energy has been adjusted to make it consistent with energy requirements that the U.S. Department of Energy's Energy Information Administration (DOE/EIA) expects in 1995 for the first-year and near-term cases and in 2000 for the long-term case. For ethanol demand, 2.0 wt% oxygen (5.7 vol% ethanol) has been assumed. Although more ethanol may be used in a given batch of fuel, it would presumably be traded in the credit market, so aggregate demand for ethanol in reformulated gasoline (RFG) would be held to the volume required for 2.0 wt% oxygenation.

The focus of this version of the analysis has been shifted to the RFGs that are anticipated under the renewable oxygenate standard (ROS). This version considers the impact of the phase-in of the ROS. (Earlier versions were published before the promulgation of the ROS.)

Other changes in this analysis include the following:

- For this analysis of energy and greenhouse gas (GHG) emissions, winter hydrocarbons (HCs) are distinguished from summer HCs so the data correspond better with winter and summer model runs. Summer, year-2000 HCs from a TM model run had been used for previous analyses of winter fuels as well as summer fuels.
- Denaturant energy is included for ethanol; an average value of 5 vol% denaturant is assumed.
- The volume percent of oxygenate that corresponds to a given weight percent of oxygen in a fuel is calculated for each of the three oxygenates on the basis of the formula published by the U.S. Environmental Protection Agency (EPA 1994b). Ethanol is assumed to be denatured (5 vol% HC), and ethers are assumed to be pure. An average gravity of 58.5° API (degrees American Petroleum Institute) is assumed for finished fuel in this calculation.
- Volumes of ethanol used in federal oxygenated gasoline (OG) are estimated by state on the basis of EPA and Information Resources, Inc. (IRI) data.

- The length of winter has been revised from 7 to 6.5 months to be consistent with the EPA's analysis.
- The front-loaded period has been shortened from 4 to 3 months because the EPA's regulatory impact analysis (RIA) uses January-March as the first part of its 197-day winter season (EPA 1994a, p. 9).
- Formerly, calculations of "current ethanol use" in RFG states included non-RFG areas. Thus, ethanol that was diverted from non-RFG areas to RFG areas within the same state was not considered to be diverted. The reasoning was that diverting ethanol from non-RFG areas to RFG areas within the same state would not overburden the ethanol transport system (because the change in destination involved such a small distance). Now, "current ethanol use" is only within RFG areas (no "free" diversion from in-state, non-RFG areas). This change was made to better reflect the EPA's intentions regarding diversion.
- RFG program participants as of the end of April 1995 are included in the demand calculations. Areas that opted out of as of April 1995 are excluded; they include all counties in Pennsylvania outside the Philadelphia Central Metropolitan Statistical Area (CMSA); Jefferson County in New York; the Albany and Buffalo CMSAs in New York; Hancock and Waldo Counties in Maine; and Kewaunee, Manitowoc, and Sheboygan Counties in Wisconsin.

APPENDIX B:
**SPREADSHEET OUTPUT ON REFORMULATED GASOLINE/
ETHANOL DEMAND**

Major Assumptions:

Transportation energy demand is distributed in proportion to population.
 Population fraction = fuel fraction
 No price elasticity for fuel demand
 No change in vehicle stock from 1993-1995
 California RFGs & OG restricted to 2.0%-wt oxygen max. NY max is 2.7%-wt oxygen.
 Non-CA RFGs: 2.1% wt. oxygen (averaging standard or compliance margin for per-gallon refiner).
 Non-CA OGs: 2.7% wt oxygen
 Trade excess renewable oxygen credits.

Reference Values:

	VALUE	RANGE NAME
Historical national gasoline demand, 1992 (MM Bbl/day): (1992 demand on 1993-adjusted basis. See Table B4, PSA 93)	7.376	
Projected national gasoline demand, 1995 (MM Bbl/day): (from EIA STEO, August, 1994 (94/3Q), Table 7.)	7.655	
Incremental gasoline demand ('92 to '95): (based on EIA data)	3.78%	INCR_DMD

Note:

EIA assumptions about energy densities of fuels differ slightly from those used in this analysis. Volumetric demands (historical and projected) from EIA have been used without adjustment because it is assumed that difference between LHVs is within plausible uncertainty bounds associated with this analysis.

RFG 1995 spillover (%):	1.00%	SPILL
OG 1995 spillover (%):	1.00%	SPILL_OG
Length of Winter-RFG period (months):	6.5	WIN_LENGTH
Length of Foreshortened Winter case (months):	3	SHORT_WIN
Average length of OG for CO control (months):	5	CO_LENGTH
Percentage RFG that is oxygenated using renewables (EtOH, ETBE): (remaining fraction is assumed to be oxygenated using MTBE)	30%	FR_ROXY

Energy Conversion Factors

Lower Heating Values (LHVs) are used for energy content of fuels.

Energy content (Btu/gal) of HC fraction of gasolines (summer):	114,500
Energy content (Btu/gal) of HC fraction of gasolines (winter):	112,700
Energy content (Btu/gal) of ETBE:	96,900
Energy content (Btu/gal) of MTBE:	93,500
Energy content (Btu/gal) of ethanol (pure):	76,100
Energy content (Btu/gal) of ethanol w/ 5% (avg.) denaturant (HCs):	78,020

Calculated multiplicative conversion factors:
(volume delta for equal energy delivery)

	SUMMER		WINTER	
	VALUE	RANGE NAME	VALUE	RANGE NAME
Gasohol to CG-eq:	0.971704	GHOL	0.986965	GHOLW
Gasoline w/ EtOH at 2.0% wt oxygen to CG-eq:			0.984887	ETOH20W
Gasoline w/ EtOH at 2.1% wt oxygen to CG-eq:			0.983960	ETOH21W
Gasoline w/ EtOH at 2.7% wt oxygen to CG-eq:			0.978401	ETOH27W
Gasoline w/ MTBE at 2.0% wt oxygen to CG-eq:	0.983431	MTBE20	0.984613	MTBE20W
Gasoline w/ MTBE at 2.1% wt oxygen to CG-eq:	0.982418	MTBE21	0.983673	MTBE21W
Gasoline w/ MTBE at 2.7% wt oxygen to CG-eq:	0.976343	MTBE27	0.978031	MTBE27W
Gasoline w/ ETBE at 2.0% wt oxygen to CG-eq:	0.983988	ETBE20		
Gasoline w/ ETBE at 2.1% wt oxygen to CG-eq:	0.983003	ETBE21		
Gasoline w/ ETBE at 2.7% wt oxygen to CG-eq:	0.977095	ETBE27		

NOTE: Divide by above factors for reciprocal conversions

Notes on conversion factors:

The weight-percentage/volume-percentage relationships for the various RFGs are derived from a formula published by EPA on 9/26/94 in an RFG Q&A update.

Denaturant in ethanol is assumed to be 5% HCs (i.e., 10%-vol EtOH provides 3.5%-wt oxygen). MTBE and ETBE are assumed to be pure.

Your mileage may vary.

Oxygen, oxygenate & energy content of RFG: (Average gravity: 58.5 deg. API)

Energy delivery per gallon RFG:

Oxygen wt. %	Volume %	Oxygenate	Summer Btu/gallon	Winter Btu/gallon
2.0%	12.8%	ETBE	112,253	110,683
	11.0%	MTBE	112,190	110,588
	5.7%	EtOH	112,316	110,619
2.1%	13.4%	ETBE	112,141	110,582
	11.6%	MTBE	112,074	110,482
	6.0%	EtOH	112,322	110,515
2.7%	17.2%	ETBE	111,467	109,977
	14.9%	MTBE	111,381	109,849
	7.7%	EtOH	111,699	109,890
3.5%	10.0%	EtOH	110,852 (Gasohol)	110,852
	2.0%	MTBE	114,080 (CG)	112,316

NOTE: Conventional gasoline (CG) is assumed to contain 2% MTBE to enhance octane.

Add'l. Properties of Oxygenates (used to calculate weight-% to volume-% conversions)

Material	Density at 60 F (lb/gal)	Wt. % Oxygen	<-- density & wt % of EtOH include effect of assumed 5% HC denaturant.
Ethanol	6.60	33.10%	
ETBE	6.22	15.66%	
MTBE	6.23	18.15%	

Source: EPA Q&A, 9/26/94.

1995 Fuel EtOH Operational Production Capacity (85% of Nameplate)				
State	Projected 1995 Gasohol Demand (w/o CAAA or CARB)	Projected 1995 Gasoline Demand (w/o CAAA or CARB)	Projected 1995 Total Gasoline- Equivalent Demand	
Alabama	0.0	291.3	1,955.5	2,241.0
Alaska	0.0	0.0	259.5	259.5
Arizona	0.0	0.0	1,833.8	1,833.8
Arkansas	0.0	25.5	1,272.4	1,297.4
California	4.5	61.7	13,868.5	13,929.0
Colorado	0.0	147.4	1,435.0	1,579.4
Connecticut	0.0	52.3	1,387.2	1,438.4
Delaware	0.0	0.0	358.0	358.0
Dist. of Col.	0.0	0.0	177.6	177.6
Florida	0.0	89.5	6,230.5	6,318.2
Georgia	0.0	23.8	3,679.3	3,702.6
Hawaii	0.0	0.0	391.4	391.4
Idaho	6.0	45.7	482.4	527.2
Illinois	597.1	1,626.4	3,096.9	4,690.7
Indiana	63.8	666.6	2,081.6	2,734.9
Iowa	317.9	533.9	876.3	1,399.5
Kansas	29.7	65.4	1,163.6	1,227.7
Kentucky	0.0	378.6	1,583.6	1,954.7
Louisiana	0.0	86.8	1,905.9	1,991.0
Maine	0.0	0.0	623.2	623.2
Maryland	0.0	0.0	2,164.3	2,164.3
Massachusetts	0.0	0.0	2,446.3	2,446.3
Michigan	0.0	534.3	3,949.8	4,473.4
Minnesota	50.1	675.6	1,530.8	2,192.9
Mississippi	0.0	0.0	1,347.5	1,347.5
Missouri	0.0	262.6	2,622.6	2,879.9
Montana	1.7	5.2	468.3	473.4
Nebraska	156.0	385.9	414.0	792.2
Nevada	0.0	74.4	634.9	707.8
New Hampshire	0.0	0.0	534.4	534.4
New Jersey	0.0	0.0	3,381.7	3,381.7
New Mexico	10.2	112.7	747.1	857.5
New York	0.0	0.0	5,695.4	5,695.4
N. Carolina	0.0	30.4	3,377.0	3,406.8
N. Dakota	33.2	57.9	306.6	363.3
Ohio	55.3	1,296.3	3,526.3	4,796.6
Oklahoma	0.0	0.0	1,760.0	1,760.0
Oregon	0.0	198.4	1,214.2	1,408.6
Pennsylvania	0.0	0.0	4,739.7	4,739.7
Rhode Island	0.0	0.0	386.4	386.4
S. Carolina	0.0	0.0	1,903.3	1,903.3
S. Dakota	5.1	165.5	250.2	412.4
Tennessee	34.0	201.7	2,387.7	2,585.4
Texas	0.0	257.2	8,604.0	8,856.0
Utah	0.0	2.6	787.6	790.1
Vermont	0.0	0.0	303.6	303.6
Virginia	0.0	107.3	3,053.0	3,158.2
Washington	3.6	438.8	2,005.7	2,435.7
West Virginia	0.0	43.6	833.7	876.4
Wisconsin	0.0	166.1	2,056.2	2,219.0
Wyoming	0.0	53.6	275.3	327.8
Total	1,368	9,165	108,370	117,351

The tables in Appendix B are in millions of gallons per year (MMGPY) and they are based on the assumption that that 30% of the O₂ in RFG is derived from renewable oxygenates.

State	Population Fractions			% OG Oxygenated EtOH (balance assumed MTBE) (derived fr. EPA & commercial data)	Volume Fed. OG Required (Absent RFG Prog)	RFG		
	Fraction requiring RFG (RFG/OG + non-OG RFG)	Fraction requiring RFG/OG during CO ctrl. pd.	Fraction requiringw/ Fed. OG during CO ctrl. pd.			non-OG RFG Demand	RFG/OG Demand	Total RFG Demand
Alabama	0	0	0	0%	0.0	0.0	0.0	0.0
Alaska	0	0	0.000	0%	0.0	0.0	0.0	0.0
Arizona	0	0	0.637	85%	502.4	0.0	0.0	0.0
Arkansas	0	0	0.021	30%	11.8	0.0	0.0	0.0
California	0.572	0.572	0.891	30%	5,306.1	4,769.0	3,403.8	8,172.7
Colorado	0	0	0.738	30%	501.5	0.0	0.0	0.0
Connecticut	1	0.460	0.460	10%	284.7	1,194.6	284.6	1,479.2
Delaware	1	0.000	0.000	0%	0.0	367.8	0.0	367.8
Dist. of Col.	1	1	1	15%	76.4	106.5	76.4	182.9
Florida	0	0	0	0%	0.0	0.0	0.0	0.0
Georgia	0	0	0	0%	0.0	0.0	0.0	0.0
Hawaii	0	0	0	0%	0.0	0.0	0.0	0.0
Idaho	0	0	0	0%	0.0	0.0	0.0	0.0
Illinois	0.643	0	0	0%	0.0	3,097.2	0.0	3,097.2
Indiana	0.109	0	0	0%	0.0	306.0	0.0	306.0
Iowa	0	0	0	0%	0.0	0.0	0.0	0.0
Kansas	0	0	0	0%	0.0	0.0	0.0	0.0
Kentucky	0.279	0	0	0%	0.0	560.8	0.0	560.8
Louisiana	0	0	0	0%	0.0	0.0	0.0	0.0
Maine	0.593	0.000	0.000	0%	0.0	379.8	0.0	379.8
Maryland	0.891	0.887	0.887	15%	826.4	1,159.7	826.2	1,985.9
Massachusetts	1	0.000	0.000	0%	0.0	2,513.0	0.0	2,513.0
Michigan	0	0	0	0%	0.0	0.0	0.0	0.0
Minnesota	0	0	0.564	90%	531.9	0.0	0.0	0.0
Mississippi	0	0	0.027	30%	15.9	0.0	0.0	0.0
Missouri	0	0	0	0%	0.0	0.0	0.0	0.0
Montana	0	0	0.0988875	30%	20.1	0.0	0.0	0.0
Nebraska	0	0	0	0%	0.0	0.0	0.0	0.0
Nevada	0	0	0.848	50%	258.2	0.0	0.0	0.0
New Hampshire	0.633	0.000	0.000	0%	0.0	347.6	0.0	347.6
New Jersey	1	0.94685928	0.9468593	5%	1,377.8	2,104.3	1,377.4	3,481.7
New Mexico	0	0	0.389	95%	143.3	0.0	0.0	0.0
New York	0.653	0.636	0.636	5%	1,558.7	2,268.4	1,558.3	3,826.7
N. Carolina	0	0	0.253	60%	371.0	0.0	0.0	0.0
N. Dakota	0	0	0	0%	0.0	0.0	0.0	0.0
Ohio	0	0	0.000	0%	0.0	0.0	0.0	0.0
Oklahoma	0	0	0	0%	0.0	0.0	0.0	0.0
Oregon	0	0	0.546	50%	330.6	0.0	0.0	0.0
Pennsylvania	0.313	0.313	0.313	5%	637.8	888.7	637.7	1,526.4
Rhode Island	1	0	0	0%	0.0	396.9	0.0	396.9
S. Carolina	0	0	0	0%	0.0	0.0	0.0	0.0
S. Dakota	0	0	0	0%	0.0	0.0	0.0	0.0
Tennessee	0	0	0.000	0%	0.0	0.0	0.0	0.0
Texas	0.430	0	0.035	90%	132.6	3,915.8	0.0	3,915.8
Utah	0	0	0.153	50%	51.9	0.0	0.0	0.0
Vermont	0	0	0	0%	0.0	0.0	0.0	0.0
Virginia	0.574	0.247	0.247	15%	335.4	1,527.4	335.3	1,862.7
Washington	0	0	0.734	80%	769.3	0.0	0.0	0.0
West Virginia	0	0	0	0%	0.0	0.0	0.0	0.0
Wisconsin	0.354	0	0.000	0%	0.0	806.8	0.0	806.8
Wyoming	0	0	0	0%	0.0	0.0	0.0	0.0
Total					14,044	26,710	8,500	35,210

State	Fed. OG Demand (non-RFG OG, net gasohol) UNDER ROS	Gasohol Demand UNDER ROS	CG Demand UNDER ROS	EtOH use in gasohol ABSENT RFG	EtOH use in OG (net of gasohol used for CO ctrl) ABSENT RFG	Total Non-RFG Ethanol Demand (g'hol+OG) ABSENT RFG
Alabama	0.0	291.3	1,955.5	29.1	0.0	29.1
Alaska	0.0	0.0	259.5	0.0	0.0	0.0
Arizona	502.4	0.0	1,347.2	0.0	31.8	31.8
Arkansas	11.5	25.5	1,261.3	2.5	0.2	2.8
California	1,903.0	0.0	4,111.0	6.2	87.0	93.2
Colorado	455.6	147.4	993.7	14.7	7.8	22.5
Connecticut	0.0	0.0	0.0	5.2	1.4	6.6
Delaware	0.0	0.0	0.0	0.0	0.0	0.0
Dist. of Col.	0.0	0.0	0.0	0.0	0.9	0.9
Florida	0.0	89.5	6,230.5	9.0	0.0	9.0
Georgia	0.0	23.8	3,679.3	2.4	0.0	2.4
Hawaii	0.0	0.0	391.4	0.0	0.0	0.0
Idaho	0.0	45.7	482.4	4.6	0.0	4.6
Illinois	0.0	581.0	1,106.4	162.6	0.0	162.6
Indiana	0.0	594.0	1,854.9	66.7	0.0	66.7
Iowa	0.0	533.9	876.3	53.4	0.0	53.4
Kansas	0.0	65.4	1,163.6	6.5	0.0	6.5
Kentucky	0.0	272.9	1,141.3	37.9	0.0	37.9
Louisiana	0.0	86.8	1,905.9	8.7	0.0	8.7
Maine	0.0	0.0	253.5	0.0	0.0	0.0
Maryland	0.0	0.0	235.6	0.0	9.2	9.2
Massachusetts	0.0	0.0	0.0	0.0	0.0	0.0
Michigan	0.0	534.3	3,949.8	53.4	0.0	53.4
Minnesota	371.3	675.6	1,171.1	67.6	23.7	91.2
Mississippi	15.9	0.0	1,332.1	0.0	0.4	0.4
Missouri	0.0	262.6	2,622.6	26.3	0.0	26.3
Montana	19.9	5.2	449.0	0.5	0.4	1.0
Nebraska	0.0	385.9	414.0	38.6	0.0	38.6
Nevada	231.6	74.4	410.6	7.4	7.6	15.1
New Hampshire	0.0	0.0	196.0	0.0	0.0	0.0
New Jersey	0.0	0.0	0.0	0.0	5.1	5.1
New Mexico	124.9	112.7	626.1	11.3	8.8	20.0
New York	0.0	0.0	1,978.8	0.0	5.8	5.8
N. Carolina	367.7	30.4	3,020.9	3.0	16.3	19.4
N. Dakota	0.0	57.9	306.6	5.8	0.0	5.8
Ohio	0.0	1,296.3	3,526.3	129.6	0.0	129.6
Oklahoma	0.0	0.0	1,760.0	0.0	0.0	0.0
Oregon	284.9	198.4	938.2	19.8	8.9	28.7
Pennsylvania	0.0	0.0	3,257.3	0.0	2.4	2.4
Rhode Island	0.0	0.0	0.0	0.0	0.0	0.0
S. Carolina	0.0	0.0	1,903.3	0.0	0.0	0.0
S. Dakota	0.0	165.5	250.2	16.6	0.0	16.6
Tennessee	0.0	201.7	2,387.7	20.2	0.0	20.2
Texas	130.5	146.5	4,774.2	25.7	8.6	34.3
Utah	51.7	2.6	737.5	0.3	1.9	2.2
Vermont	0.0	0.0	303.6	0.0	0.0	0.0
Virginia	0.0	45.8	1,301.9	10.7	2.9	13.6
Washington	633.5	438.8	1,392.1	43.9	35.7	79.5
West Virginia	0.0	43.6	833.7	4.4	0.0	4.4
Wisconsin	0.0	107.3	1,328.5	16.6	0.0	16.6
Wyoming	0.0	53.6	275.3	5.4	0.0	5.4
Total	5,104	7,596	70,697	916	267	1,183

State	EtoH use in gasohol w/in RFG areas ABSENT RFG	EtoH use in Fed.OG w/in RFG areas ABSENT RFG	Total EtoH use within RFG areas ABSENT RFG	Minimum EtoH use in RFG due to RO	Surplus (Shortfall) EtoH under ROS (vs. no ROS) in RFG areas only
Alabama	0.0	0.0	0.0	0.0	0.0
Alaska	0.0	0.0	0.0	0.0	0.0
Arizona	0.0	0.0	0.0	0.0	0.0
Arkansas	0.0	0.0	0.0	0.0	0.0
California	3.5	49.7	53.3	139.4	(86.2)
Colorado	0.0	0.0	0.0	0.0	0.0
Connecticut	5.2	0.6	5.9	25.2	(19.4)
Delaware	0.0	0.0	0.0	6.3	(6.3)
Dist. of Col.	0.0	0.9	0.9	3.1	(2.3)
Florida	0.0	0.0	0.0	0.0	0.0
Georgia	0.0	0.0	0.0	0.0	0.0
Hawaii	0.0	0.0	0.0	0.0	0.0
Idaho	0.0	0.0	0.0	0.0	0.0
Illinois	104.5	0.0	104.5	52.8	51.7
Indiana	7.3	0.0	7.3	5.2	2.0
Iowa	0.0	0.0	0.0	0.0	0.0
Kansas	0.0	0.0	0.0	0.0	0.0
Kentucky	10.6	0.0	10.6	9.6	1.0
Louisiana	0.0	0.0	0.0	0.0	0.0
Maine	0.0	0.0	0.0	6.5	(6.5)
Maryland	0.0	8.2	8.2	33.9	(25.7)
Massachusetts	0.0	0.0	0.0	42.9	(42.9)
Michigan	0.0	0.0	0.0	0.0	0.0
Minnesota	0.0	0.0	0.0	0.0	0.0
Mississippi	0.0	0.0	0.0	0.0	0.0
Missouri	0.0	0.0	0.0	0.0	0.0
Montana	0.0	0.0	0.0	0.0	0.0
Nebraska	0.0	0.0	0.0	0.0	0.0
Nevada	0.0	0.0	0.0	0.0	0.0
New Hampshire	0.0	0.0	0.0	5.9	(5.9)
New Jersey	0.0	4.8	4.8	59.4	(54.6)
New Mexico	0.0	0.0	0.0	0.0	0.0
New York	0.0	3.7	3.7	65.3	(61.6)
N. Carolina	0.0	0.0	0.0	0.0	0.0
N. Dakota	0.0	0.0	0.0	0.0	0.0
Ohio	0.0	0.0	0.0	0.0	0.0
Oklahoma	0.0	0.0	0.0	0.0	0.0
Oregon	0.0	0.0	0.0	0.0	0.0
Pennsylvania	0.0	0.7	0.7	26.0	(25.3)
Rhode Island	0.0	0.0	0.0	6.8	(6.8)
S. Carolina	0.0	0.0	0.0	0.0	0.0
S. Dakota	0.0	0.0	0.0	0.0	0.0
Tennessee	0.0	0.0	0.0	0.0	0.0
Texas	11.1	0.0	11.1	66.8	(55.7)
Utah	0.0	0.0	0.0	0.0	0.0
Vermont	0.0	0.0	0.0	0.0	0.0
Virginia	6.2	0.7	6.9	31.8	(24.9)
Washington	0.0	0.0	0.0	0.0	0.0
West Virginia	0.0	0.0	0.0	0.0	0.0
Wisconsin	5.9	0.0	5.9	13.8	(7.9)
Wyoming	0.0	0.0	0.0	0.0	0.0
Total	154	69	224	601	(377)

State	Total EtOH Use Under ROS:	Surplus (Shortfall) of EtOH within state (prod. - consump.): assuming all EtOH is used in RFG (i.e., no EtOH OG outside of RFG areas & no gasohol)	Surplus (Shortfall) of EtOH within state (prod. - consump.): assuming all EtOH is used in RFG (i.e., no EtOH OG outside of RFG areas & no gasohol)
	EtOH diverted from current us to RFG within RFG areas.assuming no diversion of No diversion fr EtOH fr non-RFG markets non-RFG areas.		
Alabama	29.1	(29.1)	0.0
Alaska	0.0	0.0	0.0
Arizona	31.8	(31.8)	0.0
Arkansas	2.8	(2.8)	0.0
California	179.3	(174.8)	(134.9)
Colorado	22.5	(22.5)	0.0
Connecticut	26.0	(26.0)	(25.2)
Delaware	6.3	(6.3)	(6.3)
Dist. of Col.	3.1	(3.1)	(3.1)
Florida	9.0	(9.0)	0.0
Georgia	2.4	(2.4)	0.0
Hawaii	0.0	0.0	0.0
Idaho	4.6	1.4	6.0
Illinois	110.9	486.2	544.3
Indiana	64.6	(0.9)	58.5
Iowa	53.4	264.5	317.9
Kansas	6.5	23.1	29.7
Kentucky	36.9	(36.9)	(9.6)
Louisiana	8.7	(8.7)	0.0
Maine	6.5	(6.5)	(6.5)
Maryland	34.9	(34.9)	(33.9)
Massachusetts	42.9	(42.9)	(42.9)
Michigan	53.4	(53.4)	0.0
Minnesota	91.2	(41.2)	50.1
Mississippi	0.4	(0.4)	0.0
Missouri	26.3	(26.3)	0.0
Montana	1.0	0.7	1.7
Nebraska	38.6	117.4	156.0
Nevada	15.1	(15.1)	0.0
New Hampshire	5.9	(5.9)	(5.9)
New Jersey	59.7	(59.7)	(59.4)
New Mexico	20.0	(9.8)	10.2
New York	67.4	(67.4)	(65.3)
N. Carolina	19.4	(19.4)	0.0
N. Dakota	5.8	27.4	33.2
Ohio	129.6	(74.4)	55.3
Oklahoma	0.0	0.0	0.0
Oregon	28.7	(28.7)	0.0
Pennsylvania	27.7	(27.7)	(26.0)
Rhode Island	6.8	(6.8)	(6.8)
S. Carolina	0.0	0.0	0.0
S. Dakota	16.6	(11.5)	5.1
Tennessee	20.2	13.8	34.0
Texas	90.1	(90.1)	(66.8)
Utah	2.2	(2.2)	0.0
Vermont	0.0	0.0	0.0
Virginia	38.5	(38.5)	(31.8)
Washington	79.5	(76.0)	3.6
West Virginia	4.4	(4.4)	0.0
Wisconsin	24.5	(24.5)	(13.8)
Wyoming	5.4	(5.4)	0.0
Total	1,560	(192)	767

Annualized ethanol utilization rate implied by satisfying ROS over period:

State	<u>Total Diversion</u>		<u>No Diversion</u>	
	(i.e., no gasohol; EtOH in OG only RFG is also required; no summer ETBE available)		(i.e., continuing to satisfy non-RFG demand for EtOH outside of RFG areas)	
	Full Winter (6.5 Months)	Front-loaded (3 Months)	Full Winter (6.5 Months)	Front-loaded (3 Months)
Alabama	0.0	0.0	53.8	116.5
Alaska	0.0	0.0	0.0	0.0
Arizona	0.0	0.0	58.6	127.0
Arkansas	0.0	0.0	5.2	11.2
California	257.4	557.7	331.1	717.3
Colorado	0.0	0.0	41.6	90.0
Connecticut	46.6	100.9	48.0	103.9
Delaware	11.6	25.1	11.6	25.1
Dist. of Col.	5.8	12.5	5.8	12.5
Florida	0.0	0.0	16.5	35.8
Georgia	0.0	0.0	4.4	9.5
Hawaii	0.0	0.0	0.0	0.0
Idaho	0.0	0.0	8.4	18.3
Illinois	97.6	211.4	204.8	443.8
Indiana	9.6	20.9	119.3	258.5
Iowa	0.0	0.0	98.6	213.6
Kansas	0.0	0.0	12.1	26.1
Kentucky	17.7	38.3	68.0	147.4
Louisiana	0.0	0.0	16.0	34.7
Maine	12.0	25.9	12.0	25.9
Maryland	62.5	135.5	64.5	139.7
Massachusetts	79.2	171.5	79.2	171.5
Michigan	0.0	0.0	98.6	213.7
Minnesota	0.0	0.0	168.4	364.9
Mississippi	0.0	0.0	0.7	1.4
Missouri	0.0	0.0	48.5	105.0
Montana	0.0	0.0	1.8	3.8
Nebraska	0.0	0.0	71.2	154.3
Nevada	0.0	0.0	27.8	60.2
New Hampshire	10.9	23.7	10.9	23.7
New Jersey	109.7	237.6	110.2	238.7
New Mexico	0.0	0.0	37.0	80.1
New York	120.5	261.2	124.4	269.6
N. Carolina	0.0	0.0	35.7	77.4
N. Dakota	0.0	0.0	10.7	23.2
Ohio	0.0	0.0	239.3	518.5
Oklahoma	0.0	0.0	0.0	0.0
Oregon	0.0	0.0	53.1	115.0
Pennsylvania	48.1	104.2	51.1	110.7
Rhode Island	12.5	27.1	12.5	27.1
S. Carolina	0.0	0.0	0.0	0.0
S. Dakota	0.0	0.0	30.6	66.2
Tennessee	0.0	0.0	37.2	80.7
Texas	123.3	267.2	166.3	360.2
Utah	0.0	0.0	4.0	8.7
Vermont	0.0	0.0	0.0	0.0
Virginia	58.7	127.1	71.2	154.2
Washington	0.0	0.0	146.9	318.2
West Virginia	0.0	0.0	8.0	17.4
Wisconsin	25.4	55.1	45.2	98.0
Wyoming	0.0	0.0	9.9	21.5
Total	1,109	2,403	2,880	6,241

Base RFG (all MTBE-oxygenated):

State	Base Summer RFG Demand (2.1% Oxy.)	Base Winter Non-OG RFG Demand (2.1% Oxy.)	Base Winter RFG/OG Demand (2.7% Oxy.)	Total Base RFG Demand
Alabama	0.0	0.0	0.0	0.0
Alaska	0.0	0.0	0.0	0.0
Arizona	0.0	0.0	0.0	0.0
Arkansas	0.0	0.0	0.0	0.0
California	3,748.1	1,021.0	3,403.3	8,172.4
Colorado	0.0	0.0	0.0	0.0
Connecticut	677.8	516.9	284.7	1,479.4
Delaware	168.7	199.1	0.0	367.8
Dist. of Col.	83.7	22.8	76.4	182.9
Florida	0.0	0.0	0.0	0.0
Georgia	0.0	0.0	0.0	0.0
Hawaii	0.0	0.0	0.0	0.0
Idaho	0.0	0.0	0.0	0.0
Illinois	1,420.7	1,676.8	0.0	3,097.5
Indiana	140.4	165.7	0.0	306.0
Iowa	0.0	0.0	0.0	0.0
Kansas	0.0	0.0	0.0	0.0
Kentucky	257.2	303.6	0.0	560.9
Louisiana	0.0	0.0	0.0	0.0
Maine	174.2	205.6	0.0	379.8
Maryland	908.8	251.0	826.4	1,986.2
Massachusetts	1,152.7	1,360.6	0.0	2,513.3
Michigan	0.0	0.0	0.0	0.0
Minnesota	0.0	0.0	0.0	0.0
Mississippi	0.0	0.0	0.0	0.0
Missouri	0.0	0.0	0.0	0.0
Montana	0.0	0.0	0.0	0.0
Nebraska	0.0	0.0	0.0	0.0
Nevada	0.0	0.0	0.0	0.0
New Hampshire	159.4	188.2	0.0	347.6
New Jersey	1,593.5	510.9	1,377.8	3,482.2
New Mexico	0.0	0.0	0.0	0.0
New York	1,751.3	517.2	1,558.8	3,827.3
N. Carolina	0.0	0.0	0.0	0.0
N. Dakota	0.0	0.0	0.0	0.0
Ohio	0.0	0.0	0.0	0.0
Oklahoma	0.0	0.0	0.0	0.0
Oregon	0.0	0.0	0.0	0.0
Pennsylvania	698.5	190.3	637.9	1,526.6
Rhode Island	182.0	214.9	0.0	396.9
S. Carolina	0.0	0.0	0.0	0.0
S. Dakota	0.0	0.0	0.0	0.0
Tennessee	0.0	0.0	0.0	0.0
Texas	1,796.1	2,120.0	0.0	3,916.2
Utah	0.0	0.0	0.0	0.0
Vermont	0.0	0.0	0.0	0.0
Virginia	853.5	674.0	335.4	1,862.9
Washington	0.0	0.0	0.0	0.0
West Virginia	0.0	0.0	0.0	0.0
Wisconsin	370.1	436.8	0.0	806.8
Wyoming	0.0	0.0	0.0	0.0
Total	16,137	10,575	8,501	35,213

Year-round use of renewables:

30% of RFG oxy'd. w/ EtOH or ETBE.

State	Summer		Winter				Total RFG
	RFG	RFG	non-OG RFG	non-OG RFG	RFG/OG	RFG/OG	
	w/ETBE (2.1% Oxy.)	w/MTBE (2.1% Oxy.)	w/EtOH (2.1% Oxy.)	w/MTBE (2.1% Oxy.)	w/EtOH (2.7% Oxy.)	w/MTBE (2.7% Oxy.)	
Alabama	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alaska	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arizona	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arkansas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
California	1,124.2	2,623.2	306.3	714.6	1,020.9	2,382.1	8,171.4
Colorado	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Connecticut	203.3	474.4	155.1	361.8	85.4	199.3	1,479.2
Delaware	50.6	118.1	59.7	139.4	0.0	0.0	367.8
Dist. of Col.	25.1	58.6	6.8	16.0	22.9	53.5	182.9
Florida	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Georgia	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hawaii	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Idaho	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Illinois	426.1	994.3	503.0	1,173.7	0.0	0.0	3,097.1
Indiana	42.1	98.2	49.7	116.0	0.0	0.0	306.0
Iowa	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kansas	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kentucky	77.2	180.0	91.1	212.5	0.0	0.0	560.8
Louisiana	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maine	52.3	121.9	61.7	143.9	0.0	0.0	379.8
Maryland	272.6	636.0	75.3	175.7	247.9	578.4	1,985.9
Massachusetts	345.7	806.7	408.1	952.3	0.0	0.0	2,512.9
Michigan	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Minnesota	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mississippi	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Missouri	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Montana	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nebraska	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nevada	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New Hampshire	47.8	111.6	56.5	131.7	0.0	0.0	347.6
New Jersey	478.0	1,115.2	153.3	357.6	413.3	964.3	3,481.7
New Mexico	0.0	0.0	0.0	0.0	0.0	0.0	0.0
New York	525.3	1,225.7	155.2	362.0	467.6	1,091.0	3,826.7
N. Carolina	0.0	0.0	0.0	0.0	0.0	0.0	0.0
N. Dakota	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ohio	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oklahoma	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Oregon	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pennsylvania	209.5	488.9	57.1	133.2	191.3	446.4	1,526.4
Rhode Island	54.6	127.4	64.5	150.4	0.0	0.0	396.9
S. Carolina	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S. Dakota	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tennessee	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Texas	538.7	1,257.1	635.9	1,483.9	0.0	0.0	3,915.6
Utah	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Vermont	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Virginia	256.0	597.4	202.2	471.7	100.6	234.8	1,862.7
Washington	0.0	0.0	0.0	0.0	0.0	0.0	0.0
West Virginia	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wisconsin	111.0	259.0	131.0	305.7	0.0	0.0	806.7
Wyoming	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	4,840	11,294	3,172	7,402	2,550	5,950	35,208

1991 Populations from 1993 Stat. Abst., Tables 31 & 42 and Appendix II.

Populations covered by RFG program are based on Opt-In as of June 1, 1994, less opt outs of late 1994 and early 1995.

OG population based on participation in the OG program during the 1993-1994 winter season.

State	1991 Total Pop. (000)	1991 Pop in RFG Areas (000)	1991 Pop Req'ing RFG/OG (000)	1991 Pop Using Non-OG RFG During CO Violations (000)	Fed OG Pop. Winter '92-93 (population is 1991 for '92-'93 areas) (000)	Gasoline Use Intensity	
						Gal Gasoline- Equiv. per Person	Fract of Nat'l Gasoline- Eq. in State
Alabama	4,091	0	0	0	0	547.8	0.019
Alaska	570	0	0	0	0	455.3	0.002
Arizona	3,748	0	0	0	2,387	489.3	0.016
Arkansas	2,373	0	0	0	50	546.7	0.011
California	30,380	17,367	17,367	0	27,079	458.5	0.119
Colorado	3,378	0	0	0	2,493	467.5	0.013
Connecticut	3,289	3,289	1,513	1,776	1,513	437.3	0.012
Delaware	680	680	0	680	0	526.5	0.003
Dist. of Col.	595	595	595	0	595	298.5	0.002
Florida	13,266	0	0	0	0	476.3	0.054
Georgia	6,623	0	0	0	0	559.1	0.032
Hawaii	1,137	0	0	0	0	344.3	0.003
Idaho	1,040	0	0	0	0	506.9	0.004
Illinois	11,541	7,418	0	7,418	0	406.4	0.040
Indiana	5,610	611	0	611	0	487.5	0.023
Iowa	2,795	0	0	0	0	500.7	0.012
Kansas	2,495	0	0	0	0	492.1	0.010
Kentucky	3,713	1,037	0	1,037	0	526.4	0.017
Louisiana	4,254	0	0	0	0	468.0	0.017
Maine	1,234	732	0	732	0	505.0	0.005
Maryland	4,859	4,330	4,312	18	4,312	445.4	0.018
Massachusetts	5,996	5,996	0	5,996	0	408.0	0.021
Michigan	9,380	0	0	0	0	476.9	0.038
Minnesota	4,432	0	0	0	2,499	494.8	0.019
Mississippi	2,593	0	0	0	71	519.7	0.011
Missouri	5,157	0	0	0	0	558.4	0.025
Montana	809	0	0	0	80	585.1	0.004
Nebraska	1,593	0	0	0	0	497.3	0.007
Nevada	1,283	0	0	0	1,088	551.7	0.006
New Hampshire	1,104	699	0	699	0	484.1	0.005
New Jersey	7,753	7,753	7,341	412	7,341	436.2	0.029
New Mexico	1,549	0	0	0	602	553.6	0.007
New York	18,055	11,782	11,484	298	11,484	315.4	0.049
N. Carolina	6,736	0	0	0	1,705	505.8	0.029
N. Dakota	635	0	0	0	0	572.2	0.003
Ohio	10,941	0	0	0	0	438.4	0.041
Oklahoma	3,175	0	0	0	0	554.3	0.015
Oregon	2,922	0	0	0	1,594	482.1	0.012
Pennsylvania	11,958	3,740	3,740	0	3,740	396.4	0.040
Rhode Island	1,005	1,005	0	1,005	0	384.4	0.003
S. Carolina	3,560	0	0	0	0	534.6	0.016
S. Dakota	704	0	0	0	0	585.8	0.004
Tennessee	4,953	0	0	0	0	522.0	0.022
Texas	17,348	7,467	0	7,467	604	510.5	0.075
Utah	1,770	0	0	0	270	446.4	0.007
Vermont	567	0	0	0	0	535.4	0.003
Virginia	6,280	3,602	1,550	2,052	1,550	502.9	0.027
Washington	5,012	0	0	0	3,680	486.0	0.021
West Virginia	1,803	0	0	0	0	486.1	0.007
Wisconsin	4,956	1,754	0	1,754	0	447.7	0.019
Wyoming	460	0	0	0	0	712.7	0.003
Total	252,160	79,857	47,902	31,955	74,737	(Average->) 465.4	1

APPENDIX C:
SUMMER REFORMULATED GASOLINE MODEL RUNS (TM)

**TABLE C.1 Refining Raw Material and Product Rate — MBPCD III C —
Summer 1995/2000 F2 — SF and 4/92 CF Case Results, NPC 1991-92
Study of U.S. Refining Industry**

Raw Materials	Base Case Q9 No FCAAA	Case S5 '95 Full Opt in	Base Case Q6 Target Δ V.O.C	Case S6 Q6 + 100% RFG	Case S6 + H ₂ EtOH	Case S13H S13 + S6 Δ V.O.C.
Raw Materials						
Domestic - S	1,223	1,223	1,985	1,985	1,985	1,985
HL	371	371	174	174	174	174
HH	226	226	692	692	692	692
Foreign - S	259	278	732	732	732	780
HL	166	172	669	669	669	669
HH	1,752	632	1,531	1,500	1,517	1,385
Subtotal Crudes	2,997	2,902	2,932	2,826	2,863	2,904
MTBE	10	88	100	184	127	139
Ethanol					30	30
Normal Butane	17	10				
Isobutane	22	33	36	40	49	53
Natural Gas to H2 Plant Feed	5	5	5	5	11	5
Methanol	8	8	4	5	5	1
Other Raw Materials	102	102	102	102	102	102
Total Raw Materials	3,162	3,148	3,178	3,163	3,187	3,234
Products						
Motor Gasolines						
Conventional	1,682	750	752			
Oxygenated						
Reformulated/Oxygenated						
Reformulated		950	945	1,713	1,198	1,205
CARB2					514	
Kero Jet/Kerosene	205	205	205	205	205	205
Diesel/No. 2 Fuels						
Diesel - LA, ULS						
Diesel - 0.05% S	580	580	580	580	580	580
No. 2 Fuel	102	102	102	102	102	102
No. 6 Fuel (1% Sul)	14	14	14	14	14	14
No. 6 Bunker	11	11	11	11	11	38
Marketable Coke - 400#	60	54	59	52	55	61
Catalytic Coke - 400#	52	50	50	49	50	50
Vacuum Gas Oil						
Benzene	2	2	2	2	2	2
Toluene	5	5	5	5	5	3
Heavy Aromatic Gaso						
Pentanes to P/C						
Natural Gasoline to P/C	38	38	38	36	37	39
Normal Butane			24	25	30	34
Isobutane						
Propane	98	92	94	86	90	92
Process Gas/C2/C2=,FOE	162	138	144	120	132	135
Other Products	271	271	271	271	271	271
(Gain)/Loss	(120)	(114)	(118)	(107)	(109)	(108)
Total Products	3,162	3,148	3,178	3,163	3,187	3,234
Crude Properties						
Gravity, °API	33.9	34.2	34.1	34.3	34.2	34.2
Sulfur, Wt%	1.18	1.11	1.14	1.09	1.11	1.13
Gasoline Demand Increase, %[1]						
Results		1.1	0.9	1.8	1.8	2.1
Target		1.1	0.8	1.9	1.9	2.1

[1] To maintain constant miles traveled with lower BTU content reformulated gasoline.

Source: Turner, Mason, and Co., NPC Refining Study (Table F-3, Jan. 8, 1993, draft).

**TABLE C.2 Energy Balance Impacts of Ethanol at Constant Δ VOC — PADD II
Summer 2000 Cases S13H vs S6[1] NPC 1991-93 Study of U.S. Refining Industry**

	MBPCD			BFOE/ Liq B	MBPCD FOE
	S6	S13H	Δ		
Products					
Gasolines					
RFG-E		512.0	512.0	0.746	382.0
RFG-M	1,712.7	1,204.7	(508.0)	0.752	(382.0)
Subtotal	<u>1,712.7</u>	<u>1,716.7</u>	<u>4.0</u>		<u>0.0</u>
Bunker	11.0	37.8	26.8	1.00	26.8
Marketable Coke, FOE	51.8	61.1	9.3	1.00	9.3
Petrochem. Gaso.	32.1	35.2	3.1	0.69	2.1
Toluene	5.0	3.0	(2.0)	0.84	(1.7)
NC4	24.9	33.7	8.8	0.68	6.0
Propane	80.0	86.0	6.0	0.60	3.6
Plant Fuel Burned, FOE	185.5	200.7	15.2	1.00	15.2
Loss (Gain)	(104.4)	(105.2)	(0.8)		0.0
Other	1,164.6	1,164.6	0.0		0.0
Total	<u>3,163.2</u>	<u>3,233.6</u>	<u>70.4</u>		<u>61.3</u>
Raw Materials					
Crude	2,326.4	2,904.4	78.0	0.92	71.8
IC4	40.4	53.2	13.2	0.65	8.6
MTBE	184.3	138.8	(45.5)	0.62	(28.2)
Methanol	5.4	0.6	(4.8)	0.62	(1.8)
Ethanol		29.4	29.4	0.38	15.0
Nat. Gas to H2 Plant	5.1	5.2	0.1	0.51	0.1
Other	102.0	102.0	0.0	1.00	0.0
Total	<u>3,163.2</u>	<u>3,233.6</u>	<u>70.4</u>		<u>65.5</u>
Net Inputs (Raw Mat less Prod)					4.2
Utilities					
Nat. Gas Purch, FOE	68.2	70.9	2.7	1.00	2.7
Elec., MMkWh/d	23.3	25.9	2.6	1.60	4.2
Plant Fuel Burned, FOE					15.2
Total Utilities Used					<u>22.1</u>
Lost Energy					
Total Net Inputs plus Utilities, FOE					26.3
Percent of Energy in Gasolines [2]					6.9%
Percent of Energy in Ethanol [3]					175%

[1] S13H VOC Reduction = 41% based on 4/92 EPA CF. Gasoline pool = 30% RFG-E + 70% RFG-M
S6 VOC Reduction = 41% based on 4/92 EPA CF. Gasoline pool = 100% RFG-M.

[2] 26.3 MBPCD FOE lost/382 MBPCD FOE in gasoline switched from RFG-M to RFG-E.

[3] 26.3 MBPCD FOE lost/15 MBPCD FOE in Ethanol used.

Source: Turner, Mason, and Co., NPC Refining Study (Table Y-1, March 30, 1993, draft).

TABLE C.3 Run Basis and Reformulated Gasoline Pool Properties IIIC — Summer 2000 F2 — 4/92 CF Case Results NPC 1991-92 Study of U.S. Refining Industry

Gasoline Specs*	Base Case Q6 Target Δ V.O.C.	Base Case Q6N = Q6+ Δ Cap. Chg.	Case VLQ40 V. Low Δ V.O.C.	Case LQ40 Low Δ V.O.C.	Case HQ40 High Δ V.O.C.	Case QN2 Q6N + 10.7% OL
Aromatics, Vol. %, Maximum Avg.						
Oxygen, Wt%, Minimum Avg.	2.1	2.1	2.1	2.1	2.1	2.1
Olefins, Vol. %, Maximum Avg.						10.7
Benzene, Vol. %, Maximum Avg.	0.7	0.7	0.7	0.7	0.7	0.7
Sulfur, WPPM, Maximum Avg.						
Reid Vapor Pressure, PSI, Min.	6.5	6.5	6.5	6.5	6.5	6.5
Reid Vapor Pressure, PSI, Max. Regulatory Cap.						
T50, °F, Maximum Avg.						
T90, °F, Maximum Avg.						
V.O.V., % Reduction	45	45	35	40	48	45
T.A.P., % Reduction	30	30	30	30	30	30
% Class C, Fixed	40	40	40	40	40	40
<u>Ethers, V% Pool</u>						
Purchased (Sold)						
Manufactured						
<u>Gasoline Pool Properties</u>						
(R+MYZ Octane, Clear*)	88.6	88.6	88.6	88.6	88.6	88.6
Aromatics, Vol. %	24.7	23.7	24.1	23.5	23.1	24.0
Ethers, Vol. %	11.7	11.7	11.7	11.7	11.7	11.7
Oxygen, Wt. %	2.1	2.1	2.1	2.1	2.1	2.1
Olefins, Vol. %	11.6	10.7	13.0	12.3	9.7	10.7
Benene, Vol. %	0.7	0.7	0.7	0.7	0.7	0.7
Sulfur, WPPM	144	141	171	173	76	137
Reid Vapor Pressure, PSI	6.5	6.5	7.2	6.8	6.5	6.5
Temperature at V/L = 20, °F	149	149	145	147	148	149
Distillation						
T10, °F	136	134	126	130	133	133
T50, °F	205	203	200	201	201	204
T90, °F	344	342	344	346	325	344
Specific Gravity	0.746	0.7444	0.7433	0.7438	0.7404	0.7450
Heat Content, MBTU/G	112.1	112.0	111.7	111.8	111.7	112.0
V.O.C., gm/mile*	0.71	0.71	0.83	0.77	0.67	0.71
% Reduction	45	45	35	40	48	45
NO _x index	0.97	0.97	0.99	0.98	0.95	0.96
% Reduction	3	3	2	2	5	4
T.A.P., mg/mile	35	34	37	36	31	35
% Reduction	33	35	31	36	31	35
* Input limit.						

Source: Turner, Mason, and Co. (Table D1-1A, 1993).

TABLE C.4 Refining Raw Material and Product Rates — MBPCD IIIC — Summer 2000 F2 — 4/92 CF Case Results, NPC 1991-92 Study of U.S. Refining Industry

Raw Materials	Base Case Q3 No. FCAAA	Base Case Q6 Target Δ V.O.C.	Base Case Q6N + Q6 Δ Cap. Chg.	Case VLQ40 V. Low Δ V.O.C.	Case LQ40 Low Δ V.O.C.	Case HQ40 High Δ V.O.C.	Case QN2 Q6N + 10.7 % OL
Raw Materials							
Domestic - S	1,985	1,985	1,985	1,985	1,985	1,985	1,985
HL	174	174	174	174	174	174	174
HH	692	692	692	692	692	692	692
Foreign - S	732	732	732	732	732	780	732
HL	669	669	669	669	669	669	669
HH	<u>1,648</u>	<u>1,636</u>	<u>1,631</u>	<u>1,500</u>	<u>1,517</u>	<u>1,385</u>	<u>1,494</u>
Subtotal Crudes	5,900	5,788	5,783	5,752	5,769	5,666	5,746
MTBE	3	132	141	152	152	282	143
Ethanol							
Normal Butane							
Isobutane	54	46	46	46	46	81	61
Natural Gas to IEZ	20	24	24	24	24	27	24
Plant Fee							
Methanol	21	35	32	29	29	32	31
Other Raw Materials	447	447	447	447	447	447	447
Total Raw Materials	<u>6,445</u>	<u>6,472</u>	<u>6,473</u>	<u>6,449</u>	<u>6,466</u>	<u>6,555</u>	<u>6,453</u>
Products							
Motor Gasolines							
Conventional	3,151	3,177	3,173	3,177	3,176		3,176
Oxygenated							
Reformulated/Oxygenated							
Reformulated		2,008	2,009	2,015	2,014	3,221	2,009
CARB2							
Kero Jet/Kerosens	686	686	686	686	686	686	686
Diesel/No. 2 Fuels							
Diesel - LA, ULS							
Diesel - 0.05% S	940	940	940	940	940	940	940
No. 2 Fuel	289	289	289	289	289	289	289
No. 6 Fuel (1% Sul)	57	57	57	57	57	57	57
No. 6 Bunker	57	57	57	57	57	76	57
Marketable Coke - 400#	180	174	174	172	173	168	172
Catalytic Coke - 400#	97	95	94	94	94	89	90
Vacuum Gas Oil							
Benzene	21	21	21	21	21	21	21
Toluene	25	25	25	25	25	25	25
Heavy Aromatic Gas							
Pentanes to P/C							
Natural Gasoline to P/C	134	134	134	134	134	135	134
Normal Butane	22	42	55	20	35	74	37
Isobutane	12	24	13	27	28	12	12
Propane	151	144	144	142	144	148	142
Process Gas/C2/C2+ FOE	365	338	337	334	337	323	332
Other Products	576	576	576	576	576	576	576
(Gain)/Loss	<u>(318)</u>	<u>(317)</u>	<u>(311)</u>	<u>(316)</u>	<u>(320)</u>	<u>(284)</u>	<u>(302)</u>
Total Products	6,445	6,472	6,473	6,449	6,466	6,555	6,453
Crude Properties							
Gravity, °API	32.8	32.9	32.8	32.9	32.9	33.0	32.9
Sulfur, Wt%	1.20	1.17	1.18	1.17	1.17	1.13	1.17
Gasoline Demand Increase: 4(1)							
Results		1.1	1.0	1.2	1.2	2.2	1.1
Target		1.1	1.0	1.2	1.2	2.1	1.1

[1] To maintain constant miles traveled with lower BTU content reformulated gasoline.

Sources: Turner, Mason, and Co. (Table D1-3, 1993).

APPENDIX D:
WINTER REFORMULATED GASOLINE MODEL RUNS (TM AND ORNL)

TABLE D.1 Energy Balance Impacts of Reformulated Gasoline PADD II
Winter 2000 Case Q9W Versus Case Q6W [1] API Study of Refining Economics

Products	MBPCD			BFOE/ Liq 8 [2]	MBPCD FOE
	Q9W	Q6W	Δ		
Motor Gasolines					
Conventional	1,658.5	657.1	(1,001.4)	0.745	(748.3)
Oxygenated		99.4	99.4	0.729	72.6
Oxy/RFG		88.7	88.7	0.728	64.4
RFG		836.0	836.0	0.729	609.4
Total Motor Gasoline	1,658.5	1,681.2	22.7		
Aviation Gasoline	3.0	3.0			
Jet A	213.0	213.0			
No. 2 Fuel	134.0	134.0			
No. 2 Diesel .05% Sulf	548.0	548.0			
No. 6 Fuel	15.4	15.4			
Carbon Black Feed	4.0	4.0			
Asphalt	103.0	103.0			
Lubes & Waxes	24.0	24.0			
Marketable Coke, FOE	64.6	58.9	(7.7)	1.00	(7.7)
Petrochem Naphtha	18.0	18.0			
Petrochem Gas Oil	18.0	18.0			
BTX	16.0	16.0			
Propane	79.7	74.9	(4.8)	0.60	(2.9)
Propylene	22.0	22.0			
Process Gas Sold	1.0	1.0			
Plant Fuel Burned	197.3	176.9	(20.4)	1.00	(20.4)
Loss (Gain)	(108.3)	(102.4)	5.9		
Total	3,013.2	3,006.9	(6.3)		(31.0)
Raw Materials					
Crude	2,707.1	2,609.4	(97.7)	0.92	(89.9)
Natural Gasoline	38.0	38.0			
Reformate (100 RON)	35.0	35.0			
Vacuum Gas Oil	27.0	27.0			
N-Butane	143.1	147.6	4.5	0.68	3.1
iso-Butane	29.2	23.5	(5.7)	0.65	(3.7)
MTBE	24.0	116.6	92.6	0.82	57.4
Methanol	3.2	3.2			
Propane	2.0	2.0			
Nat. Gas to H ₂ Plant, FOE	4.6	4.8			
Total	3,013.2	3,006.9	(6.3)		(33.1)
Net Inputs (Raw Mat. less Prod)					(2.1)
Utilities					
Nat. Gas Purchased, FOE	37.9	47.1	9.2	1.00	9.2
Elec, MMKWH/D	21.9	21.2	(0.7)	1.60	(1.1)
Plant Fuel Burned	197.3	176.9	(20.4)	1.00	(20.4)
Total Utilities Used	257.1	245.2	(11.9)		(12.3)
Loss Energy					
Total Net Inputs plus Utilities					(14.5)

[1] Q9W pool is all conventional gasoline. Q6W is full opt in of oxygenated, unreformulated and oxy/reformulated.

[2] Conversion factors indicated for variable products.

GWM
12/28/93

TURNER, MASON & COMPANY
Consulting Engineers

TABLE D.2 PADD III Phase II Winter Gasoline Blendstocks (percent)

RFG NO_x reduction minimum = 0%
 RFG TAP reduction minimum = 19.5%
 RFG production share = 62%

	RFG oxygenated with ether		30% of RFG oxygenated with ethanol		
	RFG	CG	RFG with ethanol	RFG with ether	CG
Butane	8.8	7.3	7.4	8.9	7.7
Reformate	18.4	32.4	13.1	16.1	39.2
Straight run naphtha	2.5		6.3		0.2
C5+ isomerate		16.3	1.5		15.8
FCC naphtha	35.6	21.0	36.7	43.5	12.0
Coker naphtha		2.7			2.6
Hydrocrackate	3.3	3.9		4.8	3.9
Alkylate	8.8	13.4	17.8	5.5	15.9
Polymer gasolines					2.8
Dimate					
MTBE	12.3			12.6	
TAME	0.4				
Ethanol			6.6		
Toluene/xylene	0.4			0.5	
Natural gasoline	5.5		8.5	4.0	
Pyrolysis gasoline					
Raffinates	3.8		2.1	4.1	
Other		0.2			

TABLE D.3 PADD III Phase II Raw Material Inputs (10^3 bbl/d or MBD)

	RFG oxygenated with ether	30% of RFG oxygenated with ethanol	Ethanol effect: Column 3 minus Column 2
Crude oil (1.49 wt % sulfur; 32.3° API)	5630.7	5615.2	-15.5
Natural gas (FOE)	164.0	164.0	0
Natural gasoline	113.3	113.3	0
Ethane	4.1	4.1	0
Isobutane	78.2	78.2	0
Normal butane	207.3	244.3	+37.0
Naphthas	57.1	57.1	0
Gas oils	172.8	172.8	0
MTBE	196.1	125.4	-70.7
Methanol	16.2	15.3	-0.9
Ethanol		38.4	+38.4
Total raw material inputs	6639.8	6628.0	-11.8

TABLE D.4 PADD III Phase II Outputs (10^3 bbl/d or MBD)

	RFG oxygenated with ether	30% of RFG oxygenated with ethanol	Ethanol effect: Column 3 minus Column 2
RFG oxygenated with ethanol	0	577.8	+577.8
RFG oxygenated with ethers	1926.7	1348.7	-578.0
CG	1165.9	1165.9	0
Propane	26.9	0	-26.9
Plant fuel burned	494.7	501.9	+7.2
Total output, including plant fuel burned	6752.3	6729.9	-22.4
Total saleable output (excludes plant fuel burned)	6257.6	6228.0	-29.6

APPENDIX E:
COST OF PRODUCTION ESTIMATE FOR MTBE

PROCESS: FLOMTBE1
PRICES : MTBE1995

COST OF PRODUCTION ESTIMATE FOR : MTBE
PROCESS : from Field Butanes

Million Dollars

				Capital Costs	ORIG	BOOK	REPL
Plant Startup	1990				-----	-----	-----
Analysis Date	1995			Battery Limits	226.9	226.9	226.9
Location:	USGC			Offsites	90.7	90.7	90.7
Capacity:	500.00 Thousand MT/yr				-----	-----	-----
	12,699 Barrels per Day			Total Fixed Inv.	317.6	317.6	317.6
Operating Rate:	100 percent			Working Capital			27.0
Throughput:	500.00 Thousand MT/yr						
				PRICE,	ANNUAL		
				UNITS	Dollars	Dollars	COST MM
PRODUCTION COST SUMMARY				PER MT	/UNIT	PER MT	Dollars Per Gal
RAW MATERIALS	Methanol, metric ton	0.3658	200		73.2	36.58	
	Field Butanes, metric ton	0.7655	193		147.9	73.94	
	Catalyst & Chemicals		4		4.1	2.03	
	TOTAL RAW MATERIALS				225.1	112.56	0.633
BY-PRODUCT CREDITS	Fuel Gas, MM Kcal	0.72223	11		(7.6)	(3.80)	
	TOTAL BY-PRODUCT CREDITS				(7.6)	(3.80)	(0.021)
NET RAW MATERIALS					217.5	108.76	0.612
UTILITIES	Power Purchased, KWH	40.56	0.054		2.2	1.10	
	Cooling Water, M kg	179.31	0.025		4.5	2.23	
	Steam (Gas), 600 psig, ton	0.67	12.088		8.1	4.05	
	Natural Gas, MM kcal	0.07	10.516		0.8	0.38	
TOTAL UTILITIES					15.5	7.76	0.044
VARIABLE COST OF PRODUCTION					233.0	116.52	0.655
DIRECT CASH COSTS	Labor, 32 Men	35.83	Thousand Dollars		2.3	1.15	
	Foremen, 14 Men	40.63	Thousand Dollars		1.1	0.57	
	Super., 3 Men	49.07	Thousand Dollars		0.3	0.15	
	Maint., Material & Labor	4.00	% of ISBL		18.1	9.07	
	Direct Overhead	45	% Labor & Supervision		1.7	0.84	
	TOTAL DIRECT CASH COSTS				23.6	11.78	0.066
ALLOCATED CASH COSTS	General Plant Overhead	65	% Labor & Maintenance		14.2	7.11	
	Insurance, Property Tax	1.5	% Total Fixed Investment		9.5	4.76	
	TOTAL ALLOCATED CASH COSTS				23.7	11.87	0.067
FULL CASH COST OF PRODUCTION					280.3	140.17	0.788
MONOCASH ALLOCATIONS	Depreciation	10 Years for OSBL			18.1	9.07	
		10 Years for ISBL			45.4	22.69	
NET COST OF PRODUCTION					343.9	171.93	0.967
COST PLUS 10 % RETURN ON TOTAL BOOK INV. PLUS WC					412.8	206.39	1.161
COST PLUS 20 % RETURN ON TOTAL BOOK INV. PLUS WC					481.7	240.85	1.355
COST PLUS 30 % RETURN ON TOTAL BOOK INV. PLUS WC					550.6	275.31	1.549

Source: Chem Systems, Inc. (Table A4.40, 1992).

APPENDIX F:
ETHANOL WEIGHTING FOR PROGRAMWIDE ANALYSIS

Item	Millions of Gallons per Period
1995 expected winter ethanol production capacity	741
EPA winter EtOH capacity expansion by 1996	253
Total 1996 winter ethanol capacity	994
Current winter ethanol use	641
Current excess winter ethanol (= current capacity – current use)	100
Total RFG EtOH demand	601
Total "new" EtOH available	353
Total "existing" EtOH diverted to RFG	248
Fraction existing	41.2%

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APPENDIX G:

**DELUCCHI'S BASE-CASE ESTIMATES OF GREENHOUSE GAS EMISSIONS
OF ALTERNATIVE FUELS AND SUMMARY REPORTS
ESTIMATING ENERGY TO PRODUCE ETHANOL**

TABLE G.1 Results: Fuel Cycle CO₂-Equivalent Emissions (excluding CFCs), by Fuel and Stage

GRAMS/MILE	GASOLIN	DIESEL	MeOH/LD	MeOH/HD	NG/LD	NG/HD	EVs	H2/LD	H2/HD	ETOH/LD	ETOH/HD	LPG/LD	LPG/HD
Vehicles	311.9	1736.3	253.4	1585.0	246.6	1594.2	0.0	5.5	52.9	21.9	64.3	268.6	1820.2
With wood fuels	--	--	21.1	63.8	36.9	110.1	--	--	--	21.9	64.3	--	--
Compress/liquefy	0.0	0.0	0.0	0.0	19.8	140.2	0.0	31.3	192.3	0.0	0.0	0.0	0.0
With wood fuels	--	--	0.0	0.0	17.1	121.1	--	--	--	0.0	0.0	--	--
Fuel distribution	5.8	31.1	25.0	164.3	10.1	71.8	3.7	0.4	2.5	17.0	114.6	6.2	44.2
With wood fuels	--	--	16.0	105.5	2.1	15.1	--	--	--	12.3	82.7	--	--
Fuel production	63.8	143.6	65.5	430.7	5.6	39.5	287.0	66.2	406.6	240.5	1617.1	10.6	75.5
With wood fuels	--	--	27.2	179.1	21.1	149.5	--	--	--	-66.8	-448.9	--	--
Feedstock trans.	8.3	56.4	5.6	37.0	0.0	0.0	4.3	0.14	0.88	14.6	98.3	2.4	16.8
With wood fuels	--	--	8.4	54.9	8.1	57.2	--	--	--	12.4	83.2	--	--
Feedstock + fert.	9.7	65.8	16.4	107.9	6.5	46.3	5.8	4.0	24.7	157.3	1057.6	6.9	48.7
With wood fuels	--	--	23.7	155.8	22.9	162.0	--	--	--	25.6	238.0	--	--
CH4 leaks & flares	6.7	45.3	14.3	93.9	15.4	109.0	12.1	0.0	0.0	0.0	0.0	7.5	53.3
With wood fuels	--	--	0.0	0.0	1.8	11.5	--	--	--	0.0	0.0	--	--
FIRST TOTAL	406.2	2078.5	380.2	2418.8	304.0	2001.0	312.9	107.5	679.8	451.3	2951.8	302.2	2058.6
With wood fuels	--	--	96.4	559.1	109.8	626.5	--	--	--	5.4	17.3	--	--
% CHANGES	--	--	-6.4	16.4	-25.1	-3.7	-23.0	-73.5	-67.3	11.1	42.0	-25.6	-1.0
With wood fuel	--	--	-76.3	-73.1	-73.0	-69.9	--	--	--	-98.7	-99.2	--	--
g/ml car assembly	12.4	47.2	12.4	47.2	13.0	49.8	13.4	13.6	55.4	12.4	47.2	12.7	47.6
g/ml materials	41.2	142.0	41.2	142.0	46.7	162.9	49.2	53.2	217.6	41.2	142.0	42.1	143.2
SECOND TOTAL	459.8	2267.6	433.9	2607.9	383.8	2213.7	376.5	174.3	952.8	504.9	3140.9	356.9	2249.5
With wood fuel	--	--	150.0	748.2	169.5	839.2	--	--	--	59.0	206.5	--	--
% CHANGES	--	--	-5.6	15.0	-20.9	-2.4	-18.3	-82.1	-58.0	9.8	38.5	-22.4	-0.8
With wood fuel	--	--	-67.4	-67.0	-63.1	-63.0	--	--	--	-87.2	-90.9	--	--
LDV + HDV TOTAL	568.3		564.3		474.8			221.0		663.1		470.5	
% CHANGES (w/materials + assembly)			-0.7		-16.6			-61.1		16.7		-17.2	
With wood fuels			185.9		209.7					67.9			
% CHANGES			-67.3		-63.1					-88.1			

TABLE G.2 Estimates of Energy Used to Grow Corn and Produce Ethanol (Btu Process Energy/Btu Ethanol)

Reference	Fertilizer ^a	Farming	Farm Equipment	Corn Transport	Conversion to Ethanol			Notes
					Coal	Electricity ^b	Facility	
Giampietro and Pimentel (1990)	0.33	0.16	0.13	0.06	0.90	I?	0.06	c
Jones (1989)	NE	NE	NE	NE	0.79	0.057	NE	d
Jones (1989)	NE	NE	NE	NE	0.60	0.071	NE	e
Anderson (1988)	-----0.41-0.62-----		NE	?	0.57-0.85	?	NE	f
Ferchak and Pye (1981)	-----0.46-0.53-----		I?	NE	---see Katzen (1979)---			g
Katzen Associates (1979)	-----0.44-----		NE	I	0.49	0.050	<0.01	h
Chambers et al. (1979)	0.41	0.34	0.09	0.11	0.59	I?	0.04	i
Ho (1989)	0.21	0.22	NE	NE	0.59	0.052	NE	j
Parisi (1983)	0.28	0.23	0.10	0.05	0.42	I	0.09	k
Marland and Turhollow (1990)	0.17	0.10	NE	NE	0.33-0.53	0.048	NE	l
Pimentel (1990)	0.27 (0.33)	0.27	0.07	0.006	NE	NE	NE	m
Wayman and Parekh (1990)	NE	NE	NE	NE	0.28-0.77	0.036-0.049	NE	n
Energy Fuels Development (1990)	-----0.29-----		NE	NE	0.38	0.11	NE	o
Keim, IRI (1989)	NE	NE	NE	NE	0.63	0.052	NE	p
This report	0.19	0.10	NE	0.03	0.35-0.60	0.050	NE	q

An "I" under "conversion to ethanol/electricity" means electricity use is included in the estimate of coal-energy requirement; "?" means it is not clear if the electricity-energy is included in the coal-energy or if it has simply not been counted. - "?" under "corn transport" means that it is not clear if corn transport energy has been included under farming energy or not. "I" under "corn transport" or "farm equipment" means that the energy is included under "farming" and "fertilizer." "NE" means that the particular kind of energy use is not estimated. Estimates are based on higher heating values, unless stated otherwise.

For methanol, I assume 22.7 kJ/g or 64,500 Btu/gal HHV and 19.95 kJ/g or 56,700 Btu/gal LHV; for ethanol, I assume 84,600 Btu/gal HHV and 75,670 Btu/gal LHV.

^a Does not include N₂O emissions from denitrification of fertilizer (see Appendix N).

^b Electricity counted at 3,412 Btu/kWh, unless otherwise noted.

TABLE G.2 (Cont.)

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APPENDIX H:

**ENERGY AND GREENHOUSE GAS RESULTS FOR REFORMULATED
GASOLINES ON THE BASIS OF THE USDA'S AND HO'S ESTIMATES
OF ENERGY REQUIRED TO PRODUCE ETHANOL**

**TABLE H.1 Fuel Volume and Energy Content for RFG with 2.1 wt% Oxygen: USDA Estimates
(Energy, Oil, and CO₂-Equivalent Emissions for RFG Volumes That Contain the Same Energy as Summer RFG with MTBE at 2.1 wt% Oxygen)**

FUEL TYPE	COMPO- NENTS	INITIAL VOLUME GALLONS	ENERGY CONTENT OF INITIAL VOLUME BTU	REVISED VOL TO DELIVER EQUAL BTU AS SUMMER RFG AT 2.1% OXY W/ MTBE ONLY GALLONS	REVISED ENERGY CONTENT BTU	OIL CONTENT (FEEDSTOCK) BTU	ENERGY REQUIRED TO PRODUCE RFG BTU	OIL REQUIRED TO PRODUCE RFG BTU	TOTAL ENERGY REQUIRED TO DELIVER RFG BTU	TOTAL FOSSIL ENERGY REQUIRED TO DELIVER RFG BTU	TOTAL OIL REQUIRED TO DELIVER RFG BTU	CO2- EQUIVALENT EMISSIONS G
SUMMER FUELS ANALYSIS												
RFG												
WITH MTBE	HCS	0.885	101,275	0.885	101,275	101,275	16,017	9,072	117,293	117,293	110,347	10,749
AT 2.1% O2	MTBE	0.116	10,799	0.116	10,799	641	3,216	0	14,015	14,015	641	1,094
	TOTAL	1.000	112,075	1.000	112,075	101,916	19,233	9,072	131,308	131,308	110,988	11,844
RFG												
WITH ETBE	HCS	0.866	99,157	0.865	99,098	99,098	15,457	8,661	114,554	114,554	107,758	10,479
AT 2.1% O2	ETBE	0.134	12,985	0.134	12,977	671	5,213	183	18,180	13,515	854	1,310
(NEW ETOH)	TOTAL	1.000	112,142	0.999	112,075	99,768	20,670	8,844	132,744	128,069	108,612	11,789
RFG												
WITH ETBE	HCS	0.866	99,157	0.865	99,098	99,098	15,457	8,661	114,554	114,554	107,758	10,479
AT 2.1% O2	ETBE	0.134	12,985	0.134	12,977	671	5,213	183	18,180	13,515	854	1,310
(EXISTING ETOH)	- ETOH	0.060	4,678	0.060	4,675	234	3,128	192	7,803	3,128	425	510
	CG	0.041	4,678	0.041	4,675	4,675	724	550	5,399	5,399	5,225	493
	TOTAL	0.981	112,142	0.980	112,075	104,210	18,266	9,202	130,340	130,340	113,412	11,773
CG IN PADD II												
	HCS	0.980	112,210	0.963	110,237	110,237	17,069	12,960	127,306	127,306	123,197	11,634
	MTBE	0.020	1,870	0.020	1,837	1,032	467	0	2,305	2,305	1,032	186
	TOTAL	1.000	114,080	0.982	112,075	111,269	17,537	12,960	129,611	129,611	124,229	11,821
WINTER FUELS ANALYSIS												
RFG												
WITH MTBE	HCS	0.885	99,683	0.897	101,120	101,120	13,481	7,984	114,601	114,601	109,104	10,279
AT 2.1% O2	MTBE	0.116	10,799	0.117	10,955	0	3,318	0	14,273	14,273	0	1,110
	TOTAL	1.000	110,482	1.014	112,075	101,120	16,799	7,984	128,874	128,874	109,104	11,389
RFG												
WITH ETHANOL	HCS	0.940	105,938	0.952	107,335	107,335	14,435	8,656	121,769	121,769	115,991	10,933
AT 2.1% O2	ETOH	0.060	4,678	0.061	4,740	237	3,171	194	7,911	3,171	431	517
(NEW ETOH)	TOTAL	1.000	110,616	1.013	112,075	107,572	17,606	8,851	129,680	124,940	116,422	11,450
RFG												
WITH ETHANOL	HCS	0.940	105,938	0.952	107,335	107,335	14,435	8,656	121,769	121,769	115,991	10,933
AT 2.1% O2	ETOH	0	0	0.000	0	0	0	0	0	0	0	0
(EXISTING ETOH)	CG	0.042	4,678	0.042	4,740	4,740	668	487	5,408	5,408	5,227	488
	TOTAL	0.982	110,616	0.994	112,075	112,075	15,103	9,144	127,178	127,178	121,218	11,422
CG IN PADD II												
	HCS	0.980	110,446	0.978	110,209	110,209	15,537	11,330	125,746	125,746	121,538	11,356
	MTBE	0.020	1,870	0.020	1,866	413	530	0	2,396	2,396	413	189
	TOTAL	1.000	112,316	0.998	112,075	110,622	16,067	11,330	128,141	128,141	121,952	11,545

NEW ETOH = INCREMENTALLY PRODUCED ETHANOL AS OPPOSED TO ETHANOL DIVERTED FROM EXISTING MARKETS

EXISTING ETOH = ETHANOL DIVERTED FROM EXISTING MARKETS

TABLE H.2 Fuel Volume and Energy Content for RFG with 2.7 wt% Oxygen: USDA Estimates
(Energy, Oil, and CO₂-Equivalent Emissions for RFG Volumes That Contain the Same Energy as Summer RFG with MTBE at 2.1 wt% Oxygen)

FUEL TYPE	COMPO- NENTS	INITIAL VOLUME GALLONS	ENERGY CONTENT OF INITIAL VOLUME BTU	REVISED VOL TO DELIVER EQUAL BTU AS SUMMER RFG AT 2.1% OXY W/ MTBE ONLY GALLONS	REVISED ENERGY CONTENT (FEEDSTOCK) BTU	OIL CONTENT BTU	ENERGY REQUIRED TO PRODUCE RFG BTU	OIL REQUIRED TO PRODUCE RFG BTU	TOTAL ENERGY REQUIRED TO DELIVER RFG BTU	TOTAL FOSSIL ENERGY REQUIRED TO DELIVER RFG BTU	TOTAL OIL REQUIRED TO DELIVER RFG BTU	CO2- EQUIVALENT EMISSIONS G
RFG												
WITH MTBE	HCs	0.852	95,964	0.869	97,908	97,908	13,053	7,730	110,961	110,961	105,639	9,953
AT 2.7% O2	MTBE	0.149	13,885	0.152	14,166	0	4,291	0	18,457	18,457	0	1,435
	TOTAL	1.000	109,849	1.020	112,075	97,908	17,344	7,730	129,418	129,418	105,639	11,388
RFG												
WITH ETHANOL	HCs	0.923	104,045	0.940	105,975	105,975	14,252	8,547	120,227	120,227	114,522	10,795
AT 2.7% O2	ETOH	0.077	5,988	0.078	6,099	305	4,080	250	10,180	4,080	555	665
(NEW ETOH)	TOTAL	1.000	110,033	1.019	112,075	106,280	18,332	8,797	130,407	124,308	115,077	11,460
RFG												
WITH ETHANOL	HCs	0.923	104,045	0.940	105,975	105,975	14,252	8,547	120,227	120,227	114,522	10,795
AT 2.7% O2	ETOH	0	0	0.000	0	0	0	0	0	0	0	0
(EXISTING ETOH)	CG	0.053	5,988	0.054	6,099	6,099	860	627	6,959	6,959	6,726	628
	TOTAL	0.976	110,033	0.994	112,075	112,075	15,112	9,174	127,186	127,186	121,248	11,423
CG IN PADD II												
	HCs	0.980	110,446	0.978	110,209	110,209	15,537	11,330	125,746	125,746	121,538	11,356
	MTBE	0.020	1,870	0.020	1,866	413	530	0	2,396	2,396	413	189
	TOTAL	1.000	112,316	0.998	112,075	110,622	16,067	11,330	128,141	128,141	121,952	11,545

NEW ETOH = INCREMENTALLY PRODUCED ETHANOL AS OPPOSED TO ETHANOL DIVERTED FROM EXISTING MARKETS

EXISTING ETOH = ETHANOL DIVERTED FROM EXISTING MARKETS

TABLE H.3 Fuel Volume and Energy Content for RFG with 2.1 wt% Oxygen: Ho Estimates
(Energy, Oil, and CO₂-Equivalent Emissions for RFG Volumes That Contain the Same Energy as Summer RFG with MTBE at 2.1 wt% Oxygen)

FUEL TYPE	COMPO- NENTS	INITIAL VOLUME GALLONS	ENERGY CONTENT OF INITIAL VOLUME BTU	REVISED VOL TO DELIVER EQUAL BTU AS SUMMER RFG AT 2.1% OXY W/ MTBE ONLY GALLONS	REVISED ENERGY CONTENT BTU	OIL CONTENT (FEEDSTOCK) BTU	ENERGY REQUIRED TO PRODUCE RFG BTU	OIL REQUIRED TO PRODUCE RFG BTU	TOTAL ENERGY REQUIRED TO DELIVER RFG BTU	TOTAL FOSSIL ENERGY REQUIRED TO DELIVER RFG BTU	TOTAL OIL REQUIRED TO DELIVER RFG BTU	CO2- EQUIVALENT EMISSIONS G
SUMMER FUELS ANALYSIS												
RFG												
WITH MTBE	HCS	0.885	101275	0.885	101275	101275	16017	9072	117293	117293	110347	10749
AT 2.1% O2	MTBE	0.116	10799	0.116	10799	641	3216	0	14015	14015	641	1094
	TOTAL	1.000	112075	1.000	112075	101916	19233	9072	131308	131308	110988	11844
RFG												
WITH ETBE	HCS	0.866	99157	0.865	99098	99098	15457	8661	114554	114554	107758	10479
AT 2.1% O2	ETBE	0.134	12985	0.134	12977	671	7037	702	20014	15338	1372	1518
(NEW ETOH)	TOTAL	1.000	112142	0.999	112075	99768	22493	9362	134568	129892	109131	11997
RFG												
WITH ETBE	HCS	0.866	99157	0.865	99098	99098	15457	8661	114554	114554	107758	10479
AT 2.1% O2	ETBE	0.134	12985	0.134	12977	671	7037	702	20014	15338	1372	1518
(EXISTING ETOH)	- ETOH	0.060	4678	0.060	4675	234	5035	734	9711	5035	968	686
	CG	0.041	4678	0.041	4675	4675	724	550	5399	5399	5225	493
	TOTAL	0.981	112142	0.980	112075	104210	18182	9178	130256	130256	113388	11804
CG IN PADD II												
	HCS	0.980	112210	0.963	110237	110237	17069	12960	127306	127306	123197	11634
	MTBE	0.020	1870	0.020	1837	1032	467	0	2305	2305	1032	186
	TOTAL	1.000	114080	0.982	112075	111269	17537	12960	129611	129611	124229	11821
WINTER FUELS ANALYSIS												
RFG												
WITH MTBE	HCS	0.885	99683	0.897	101120	101120	13481	7984	114601	114601	109104	10279
AT 2.1% O2	MTBE	0.116	10799	0.117	10955	0	3318	0	14273	14273	0	1110
	TOTAL	1.000	110482	1.014	112075	101120	16799	7984	128874	128874	109104	11389
RFG												
WITH ETHANOL	HCS	0.940	105938	0.952	107335	107335	14435	8656	121769	121769	115991	10933
AT 2.1% O2	ETOH	0.060	4678	0.061	4740	237	5105	744	9845	5105	981	695
(NEW ETOH)	TOTAL	1.000	110616	1.013	112075	107572	19540	9400	131614	126874	116972	11629
RFG												
WITH ETHANOL	HCS	0.940	105938	0.952	107335	107335	14435	8656	121769	121769	115991	10933
AT 2.1% O2	ETOH	0	0	0.000	0	0	0	0	0	0	0	0
(EXISTING ETOH)	CG	0.042	4678	0.042	4740	4740	668	487	5408	5408	5227	488
	TOTAL	0.982	110616	0.994	112075	112075	15103	9144	127178	127178	121218	11422
CG IN PADD II												
	HCS	0.980	110446	0.978	110209	110209	15537	11330	125746	125746	121538	11356
	MTBE	0.020	1870	0.020	1866	413	530	0	2396	2396	413	189
	TOTAL	1.000	112316	0.998	112075	110622	16067	11330	128141	128141	121952	11545

NEW ETOH = INCREMENTALLY PRODUCED ETHANOL AS OPPOSED TO ETHANOL DIVERTED FROM EXISTING MARKETS

EXISTING ETOH = ETHANOL DIVERTED FROM EXISTING MARKETS

TABLE H.4 Fuel Volume and Energy Content for RFG with 2.7 wt% Oxygen: Ho Estimates
(Energy, Oil, and CO₂-Equivalent Emissions for RFG Volumes That Contain the Same Energy as Summer RFG with
MTBE at 2.1 wt% Oxygen)

FUEL TYPE	COMPO- NENTS	INITIAL VOLUME GALLONS	ENERGY CONTENT OF INITIAL VOLUME BTU	REVISED VOL TO DELIVER EQUAL BTU AS SUMMER RFG AT 2.1% OXY W/ MTBE ONLY GALLONS	REVISED ENERGY CONTENT BTU	OIL CONTENT (FEEDSTOCK) BTU	ENERGY REQUIRED TO PRODUCE RFG BTU	OIL REQUIRED TO PRODUCE RFG BTU	TOTAL ENERGY REQUIRED TO DELIVER RFG BTU	TOTAL FOSSIL ENERGY REQUIRED TO DELIVER RFG BTU	TOTAL OIL REQUIRED TO DELIVER RFG BTU	CO ₂ - EQUIVALENT EMISSIONS G
RFG												
WITH MTBE	HCS	0.852	95964	0.869	97908	97908	13053	7730	110961	110961	105639	9953
AT 2.7% O2	MTBE	0.149	13885	0.152	14166	0	4291	0	18457	18457	0	1435
	TOTAL	1.000	109849	1.020	112075	97908	17344	7730	129418	129418	105639	11388
RFG												
WITH ETHANOL	HCS	0.923	104045	0.940	105975	105975	14252	8547	120227	120227	114522	10795
AT 2.7% O2	ETOH	0.077	5988	0.078	6099	305	6569	958	12668	6569	1263	895
(NEW ETOH)	TOTAL	1.000	110033	1.019	112075	106280	20821	9504	132895	126796	115785	11690
RFG												
WITH ETHANOL	HCS	0.923	104045	0.940	105975	105975	14252	8547	120227	120227	114522	10795
AT 2.7% O2	ETOH	0	0	0.000	0	0	0	0	0	0	0	0
(EXISTING ETOH)	CG	0.053	5988	0.054	6099	6099	860	627	6959	6959	6726	628
	TOTAL	0.976	110033	0.994	112075	112075	15112	9174	127186	127186	121248	11423
CG IN PADD II												
	HCS	0.980	110446	0.978	110209	110209	15537	11330	125746	125746	121538	11356
	MTBE	0.020	1870	0.020	1866	413	530	0	2396	2396	413	189
	TOTAL	1.000	112316	0.998	112075	110622	16067	11330	128141	128141	121952	11545

NEW ETOH = INCREMENTALLY PRODUCED ETHANOL AS OPPOSED TO ETHANOL DIVERTED FROM EXISTING MARKETS

EXISTING ETOH = ETHANOL DIVERTED FROM EXISTING MARKETS

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