

Committee D02 on Petroleum Products and Lubricants

Research Report D02: 1347

Research Report on Reformulated Spark-Ignition Engine Fuel

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1. Scope

1.1 This Research Report is published to provide information on the requirements of reformulated gasoline for ground vehicles equipped with spark-ignition engines.

1.2 This Research Report describes various characteristics of reformulated fuels required for use by automotive vehicles in severe and extreme ozone nonattainment areas as designated by the Clean Air Act Amendments (CAAA) of 1990 and in those ozone nonattainment areas that opt to require reformulated fuels. This Research Report also describes limitations, where adopted, on fuel composition and properties established by federal regulations or the State of California. This Research Report neither necessarily

includes all types of fuels that are satisfactory for automotive vehicles, nor necessarily excludes fuels that may perform unsatisfactorily under certain operating conditions or in certain equipment. The significance of each property of this Research Report is shown in Appendix X1.

1.3 The reformulated fuels covered in this Research Report are unleaded gasolines, generally blended with oxygenates such as alcohols or ethers. The requirements of federal reformulated fuels have been established by the U. S. Environmental Protection Agency (EPA). In the State of California, requirements for California reformulated fuels have been set by the California Air Resources Board (CARB). Under provisions of the CAAA, other areas may petition the EPA to require the use of reformulated fuels that have either federal or California reformulated fuel properties.

1.4 This Research Report provides information on states that require cleaner burning gasoline or reformulated gasoline for certain areas of the state. In addition to California, states adopting cleaner burning gasoline standards are Arizona (Maricopa County), Nevada (Clark County), Georgia (Atlanta Area), and Alabama (Jefferson and Shelby Counties). These states have established varying limits on vapor pressure, sulfur, olefins, aromatics, oxygen/oxygenates, and other properties, (or combinations thereof), or have adopted certain provisions of the Federal or California reformulated gasoline program. Fuel requirements for state reformulated gasoline programs are provided in Appendix X3.

1.5 The various characteristics of reformulated fuels described in this Research Report are legal requirements imposed by regulatory agencies to lower exhaust and evaporative emissions from automotive vehicles. In addition to these legal requirements, reformulated fuels should also meet the performance requirements found in ASTM D 4814 (Standard Specification for Automotive Spark-Ignition Engine Fuel).

1.6 This Research Report represents a description of reformulated fuel as of the date of publication¹.

This Research Report is under continual review, which will result in revisions based on changes in regulations, fuels, automotive requirements, or test methods, or a combination thereof. All users of this Research Report, therefore, should refer to the latest edition and should refer to the regulations published in the Code of Federal Regulations, The Federal Register, and the California Code of Regulations for guidance on compliance. Contact the EPA for the latest version of EPA rules and requirements. Users should also refer to state regulations for recent changes. Some test methods are not acceptable to all regulatory agencies.

1.7 Enforcement of most of the federal regulations for individual properties described in this Research Report occurs only at the refinery or import facility. Only the per gallon maximum or minimum limits for averaging (see Table 1) and the requirement for the addition of additives can be enforced in the downstream distribution system of terminals and retail outlets. Users of this Research Report should contact the EPA for information regarding enforcement policies in the distribution system. California regulations apply at all levels of the distribution system.

1.8 The values stated in SI units are the standard. Values given in parentheses (U.S. customary units) are those specified by the regulatory agencies.

2. Referenced Documents

2.1 ASTM Standards

- D 86 Test Method for Distillation of Petroleum Products
- D 323 Test Method for Vapor Pressure of Petroleum Products (Reid Method)
- D 1159 Test Method for Bromine Number of Petroleum Distillates and Commercial Aliphatic Olefins by Electrometric Titration
- D 1319 Test Method for Hydrocarbon Types in Liquid Petroleum Products by Fluorescent Indicator Adsorption
- D 2622 Test Method for Sulfur in Petroleum Products by X-Ray Spectrometry
- D 3120 Test Method for Trace Quantities of Sulfur in Light Liquid Petroleum Hydrocarbons by Oxidative Microcoulometry
- D 3606 Test Method for Determination of Benzene and Toluene Content of Finished Motor and Aviation Gasoline by Gas Chromatography
- D 4045 Test Method for Sulfur in Petroleum Products by Hydrogenolysis and Rateometric Colorimetry
- D 4053 Test Method for Benzene in Motor and Aviation Gasoline by Infrared Spectroscopy
- D 4294 Test Method for Sulfur in Petroleum Products by Energy-Dispersive X-Ray Fluorescence Spectroscopy

- D 4420 Test Method for Aromatics in Finished Gasoline by Gas Chromatography
- D 4814 Specification for Automotive Spark-Ignition Engine Fuel
- D 4815 Test Method for Determination of MTBE, ETBE, TAME, DIPE, *tertiary*-Amyl Alcohol and C₁ to C₄ Alcohols in Gasoline by Gas Chromatography
- D 4953 Test Method for Vapor Pressure of Gasoline and Gasoline-Oxygenate Blends (Dry Method)
- D 5190 Test Method for Vapor Pressure of Petroleum Products (Automatic Method)
- D 5191 Test Method for Vapor Pressure of Petroleum Products (Mini Method)
- D 5453 Test Method for Total Sulfur in Light Hydrocarbons, Motor Fuels and Oils by Ultraviolet Fluorescence
- D 5580 Test Method for the Determination of Benzene, Toluene, Ethylbenzene, p/m-Xylene, o-Xylene, C₉ and Heavier Aromatics and Total Aromatics in Finished Gasoline by Gas Chromatography
- D 5599 Test Method for the Determination of Oxygenates in Gasoline by Gas Chromatography and Oxygen Selective Flame Ionization Detection
- D 5622 Test Method for the Determination of Total Oxygen in Gasoline and Methanol Fuels by Reductive Pyrolysis
- D 5769 Test Method for Determination of Benzene, Toluene and Total Aromatics in Finished Gasolines by Gas Chromatography/Mass Spectrometry
- D 5845 Test Method for Determination of MTBE, ETBE, TAME, DIPE, Methanol, Ethanol and *tert*-Butanol in Gasoline by Infrared Spectroscopy
- D 5500 Test Method for Vehicle Evaluation of Unleaded Automotive Spark-Ignition Engine Fuel for Intake Valve Deposit Formation
- D 5598 Test Method for Evaluating Unleaded Automotive Spark-Ignition Engine Fuel for Electronic Port Fuel Injector Fouling
- D 6920 Test Method for Total Sulfur in Napthas, Distillates, Reformulated Gasolines, Diesels, Biodiesels, and Motor Fuels by Oxidative Combustion and Electrochemical Detection
- D 7039 Test Method for Sulfur in Gasoline and Diesel Fuel by Monochromatic Wavelength Dispersive X-ray Fluorescence Spectrometry

¹ If there is any doubt as to the latest edition of this Research Report, contact ASTM headquarters.

3. Terminology

3.1 Definitions

3.1.1 *gasoline, n* - a volatile mixture of liquid hydrocarbons, generally containing small amounts of additives, suitable for use as a fuel in spark-ignition, internal combustion engines.

3.1.2 *gasoline-alcohol blend, n* - a fuel consisting primarily of gasoline along with a substantial amount (more than 0.35 mass percent oxygen, or more than 0.15 mass percent oxygen if methanol is the only oxygenate) of one or more alcohols.

3.1.3 *gasoline-ether blend, n* - a fuel consisting primarily of gasoline along with a substantial amount (more than 0.35 mass percent oxygen) of one or more ethers.

3.1.4 *gasoline-oxygenate blend, n* - a fuel consisting primarily of gasoline along with a substantial amount (more than 0.35 mass percent oxygen, or more than 0.15 mass percent oxygen if methanol is the only oxygenate) of one or more oxygenates.

3.1.5 *oxygenate, n* - an oxygen-containing, ashless, organic compound, such as an alcohol or ether, which can be used as a fuel or fuel supplement.

3.2 Description of Terms Specific to This Research Report:

3.2.1 *Adjusted VOC gasoline* - a gasoline that contains 10 volume percent ethanol, or RBOB intended for blending with 10 volume percent ethanol, that is intended for use in the VOC-Control Region 2 RFG covered areas of Chicago and Milwaukee, and is designated by the refiner as "adjusted VOC gasoline" subject to less stringent Federal EPA VOC standards.

3.2.2 *Adjusted VOC gasoline standards* - the applicable VOC performance standards in § 80.41 for adjusted VOC gasoline intended for use in or sold for use by an ultimate consumer in VOC-Control Region 2 in the RFG covered areas of Chicago and Milwaukee.

3.2.3 *alternative gasoline formulation* - a gasoline or gasoline-oxygenate blend that does not meet the fuel parameter requirements for California Phase 3 Reformulated Gasoline (CaRFG3) but has been certified by CARB to result in equivalent emissions reductions, by CARB's acceptance of emissions data from vehicle testing or from prediction by the California Predictive Model.

3.2.4 *anti-dumping* - a provision of the 1990 Clean Air Act Amendments intended to ensure that fuel components which increase emissions, and are removed or limited in reformulated gasoline, are not added or "dumped" into conventional gasoline.

3.2.5 *averaging* - a process whereby a value for a parameter that is above the standard in one reformulated gasoline batch can be offset by a value that is below the standard in another batch for a given refiner or importer.

3.2.6 *average limit* - a restriction on a reformulated gasoline parameter that shall be met on average during a yearly or seasonal reporting period.

3.2.7 *baseline gasoline* - gasoline for a given refiner whose properties are nominally representative of all the U.S. gasoline sold during 1990 as defined by the Clean Air Act Amendments of 1990.

3.2.8 *California Phase 2 Reformulated Gasoline (CaRFG2)* - a gasoline or gasoline-oxygenate blend that met the specifications and emission reduction requirements established by the California Air Resources Board, in effect from 1996 through 2003; frequently referred to as Cleaner Burning Gasoline (CBG).

3.2.9 *California Phase 3 Reformulated Gasoline (CaRFG3)* - a gasoline or gasoline-oxygenate blend that meets the specifications and emission reduction requirements established by the California Air Resources Board, effective December 31, 2003; frequently referred to as Cleaner Burning Gasoline (CBG).

3.2.10 *cap* - for California Phase 3 Reformulated Gasoline (CaRFG3), an absolute limit (maximum or minimum) which shall not be exceeded by any gallon of reformulated gasoline. This terminology is analogous to federal per gallon maxima or minima.

3.2.11 *Complex Model* - a set of specifications and equations developed by the EPA that predict volatile organic compound, oxides of nitrogen, and toxic air pollutant reductions based on the following parameters: aromatics, benzene, olefins, sulfur, oxygenate type and content, percent evaporated at 200°F, percent evaporated at 300°F, and vapor pressure.

3.2.12 *conventional gasoline* - gasoline which does not meet the requirements of reformulated gasoline or is not intended for sale in a federal RFG area.

3.2.13 *covered area* - a geographic area in which only reformulated gasoline shall be sold or dispensed to ultimate consumers.

3.2.14 *deposit control additive* - material added to gasoline to prevent or remove deposits in the entire engine intake system.

3.2.15 *E200* - the volume percent gasoline evaporated at 200°F during distillation according to Test Method D 86.

3.2.16 *E300* - the volume percent gasoline evaporated at 300°F during distillation according to Test Method D 86.

3.2.17 *flat limit* - for California Phase 3 Reformulated Gasoline (CaRFG3), a limit for a fuel parameter that applies to each batch of reformulated gasoline; analogous to the federal per gallon standard.

3.2.18 *Mobile Source Air Toxics (MSAT)* - Hazardous air pollutants, including benzene, emitted by

motor vehicles and fuels and subject to the specifications and emission reduction requirements for air toxics established by the U.S. EPA for reformulated and conventional gasoline.

3.2.19 *NO_x* - oxides of nitrogen emitted by automotive vehicles.

3.2.20 *opt-in* - a provision of the Clean Air Act Amendments allowing areas other than those mandated to request the EPA to require the use of reformulated gasoline.

3.2.21 *opt-out* - a provision allowing areas which had previously opted into the federal reformulated gasoline program to be removed from the program.

3.2.22 *per gallon maximum* - the highest value that a reformulated gasoline parameter shall have in any batch when averaging; similar to the California Reformulated Gasoline (CaRFG) maximum cap.

3.2.23 *per gallon minimum* - the lowest value that a reformulated gasoline parameter shall have in any batch when averaging; similar to the California Reformulated Gasoline (CaRFG) minimum cap.

3.2.24 *per gallon standard* - a limit for a gasoline parameter that shall be met for each batch of gasoline during the reporting period; similar to the California Reformulated Gasoline (CaRFG) flat limit.

3.2.25 *Phase I RFG (Complex Model)* - a gasoline-oxygenate blend that meets the specifications and emission reduction requirements established by the U.S. EPA, required January 1, 1998. Could be used beginning January 1, 1995.

3.2.26 *Phase II RFG (Complex Model)* - a gasoline-oxygenate blend that meets the specifications and emission reduction requirements established by the U.S. EPA, required January 1, 2000.

3.2.27 *Predictive Model* - a set of equations developed by CARB which predict the change in exhaust hydrocarbon emissions, exhaust emissions of oxides of nitrogen, and the combined exhaust emissions of four toxic air contaminants (1,3-butadiene, benzene, formaldehyde and acetaldehyde). Under CaRFG3, the model was expanded to include an evaporative emissions element and CO credit mechanism.

3.2.28 *reformulated gasoline (RFG)* - a gasoline or gasoline-oxygenate blend certified to meet the specifications and emission reduction requirements established by the Clean Air Act Amendments of 1990, (as amended by the Energy Policy Act of 2005), required for use in automotive vehicles in extreme and severe ozone non-attainment areas and those areas which opt to require reformulated gasoline.

3.2.29 *reformulated gasoline blendstock for oxygenate blending (RBOB)* - a petroleum product which, when blended with an oxygenate, meets the definition of reformulated gasoline, and to which the

oxygenate is added other than by a refiner or importer.

3.2.30 *renewable fuel standard (RFS)* - the annual volume of renewable fuel mandated to be used in gasoline and diesel fuel under Section 202 of the Energy Independence and Security Act of 2007 (EISA).

3.2.31 *Renewable Identification Number (RIN)* - a 38-character numeric code required by EPA under the RFS program and assigned to every batch of renewable fuel produced or imported. Refiners, importers, and blenders obligated to meet the renewable volume requirement must acquire sufficient RINs on an annual basis to demonstrate compliance with their volume obligation.

3.2.32 *RVP* - the designation for gasoline vapor pressure used by the EPA. The test method used for measuring this property, however, is not D 323, and therefore RVP does not represent a true Reid vapor pressure.

3.2.33 *Simple Model* - a set of specifications and equations developed by the EPA that predict volatile organic compound and toxic air pollutant reductions from reformulated gasoline based upon the following fuel parameters: aromatics, benzene and oxygen contents, and vapor pressure; the Simple Model expired 12/31/97 and is no longer used.

3.2.34 *Statutory Baseline* - A set of fuel properties, nominally representative of US gasoline in 1990, used to evaluate emissions improvements of reformulated gasoline.

3.2.35 *Tier 2/Sulfur Content Standards* - Gasoline sulfur content standards for refiners and importers established by the U.S. Environmental Protection Agency. The standards apply to all reformulated gasoline, reformulated gasoline blendstock for oxygenate blending (RBOB), and conventional gasoline beginning with the January 1, 2004 averaging period.

3.2.36 *toxics* - In federal regulations, the sum of five toxic air pollutants (acetaldehyde, benzene, 1,3-butadiene, formaldehyde and polycyclic organic matter) emitted by automotive vehicles; California regulations apply to the sum of the first four only.

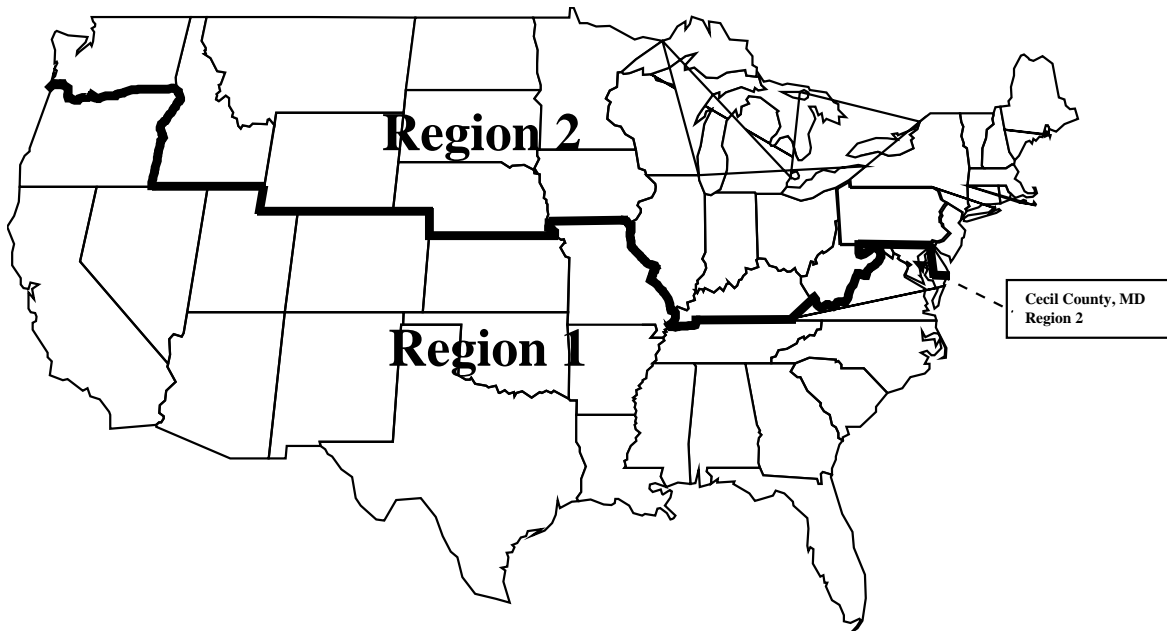
3.2.37 *VOC* - volatile organic compounds consisting of non-methane, non-ethane hydrocarbons and oxygenated hydrocarbons emitted by automotive vehicles.

3.2.38 *VOC Control Region 1* - a designation assigned by the EPA to roughly the southern half of the 48 contiguous United States, sometimes referred to as Region B (See Figure 1).

3.2.39 *VOC Control Region 2* - a designation assigned by the EPA to roughly the northern half of the 48 contiguous United States; sometimes referred to as Region C (See Figure 1).

Figure 1

U.S. EPA VOC CONTROL REGIONS



4. Reformulated Gasoline Performance Requirements

4.1 Reformulated Gasoline

4.1 In addition to the limits specified below, reformulated spark-ignition engine fuel should also meet the performance requirements of ASTM D 4814. Reformulated gasoline (federal) certified under Phase II of the Complex Model shall conform to the requirements in Table 1. Refiners were required to use the Complex Model starting January 1, 1998. The Simple Model was used from 1995 through 1997.) (Phase I complex model standards, in effect during the

period January 1, 1998 through December 31, 1999, are discussed in Appendix X4). Compliance with federal Phase II performance standards began January 1, 2000.

4.1.1 Starting December 31, 2003, all gasoline sold in California is required to comply with CARB Phase 3 Reformulated Gasoline (CaRFG3) standards. Refer to Table 6 for a list of the CaRFG3 limits. Refer to Section 4.4 for a description of the CaRFG3 standards. Refer to Section 6 for appropriate test methods.

Table 1

EPA COMPLEX MODEL STANDARDS FOR FEDERAL RFG

Emissions Reductions & Properties	Phase II Standards (2000+)		
	Per-Gallon	Average	
		Average Limit	Per-Gallon Limit
VOC Reduction, %^A			
VOC-Control Region 1, minimum	27.5	29.0	25.0 ^C
Adjusted VOC gasoline designated for VOC-Control Region 2, min. ^B	23.9	25.4	21.4 ^C
All other gasoline designated for VOC-Control Region 2, min.	25.9	27.4	23.4 ^C
NOx Reduction, %			
VOC control period, min.	5.5	6.8	N/A
Non-VOC control period, min	0	1.5	N/A
Toxics Reduction, %, min.	20.0	21.5	N/A
Benzene, volume %, max.	1.00	0.95	1.30

^A VOC reductions apply to VOC control period only. In addition, under the Complex Model, RFG Covered Areas are subject, during VOC control periods, to reduction requirements as well as Federal Phase II volatility standards.

^B Effective July 17, 2001, EPA promulgated a Final Rule adjusting the volatile organic compound (VOC) performance standard under Phase II of the reformulated gasoline (RFG) program for ethanol RFG blends containing 3.5 weight percent oxygen (10 volume percent ethanol) sold in the Chicago and Milwaukee RFG areas. In order for “adjusted VOC gasoline” to qualify for the regulatory treatment specified in § 80.41(e) and (f), reformulated gasoline must contain denatured, anhydrous ethanol. The concentration of the ethanol, excluding the required denaturing agent, must be at least 9% and no more than 10% (by volume) of the gasoline. See Federal Register, Vol. 66, No. 137, July 17, 2001, pages 37156-37165.

^C Under Phase II of the complex model, the minimum per-gallon VOC emissions performance reduction standards are 25.0% and 23.4% for RFG used in VOC Control Regions 1 and 2 respectively. As a matter of enforcement discretion, EPA is recognizing an enforcement tolerance of 2% for these VOC emissions performance standards in the case of gasoline found at locations downstream of the refinery level. Beginning with the year 2000, EPA considers gasoline downstream of the refinery to have met the applicable VOC emissions performance standard if the emissions performance is 23.0% or 21.4% used in VOC Control Regions 1 and 2, respectively.

4.2 Federal Reformulated Gasoline

4.2.1 General requirements (under the 1990 Clean Air Act Amendments as amended by the Energy Policy Act of 2005) for Federal Reformulated Gasoline are a maximum 1.0 percent by volume benzene content, limits on heavy metals, and shall not cause an increase in emissions of oxides of nitrogen. A requirement for deposit control additives in all gasolines was promulgated in 1994 and became effective January 1, 1995 (59 FR 54678, November 1, 1994). Certification standards for these additives were promulgated in 1996 and became effective on July 1, 1997 for gasoline blenders and distributors and on August 1, 1997 for gasoline retailers (61 FR 35310, July 5, 1996).

4.2.1.1 On August 8, 2005, the President signed into law the Energy Policy Act of 2005 (P.L. 109-58). This legislation made significant revisions to the Federal RFG program, and established a Renewable Fuel Standard (RFS) mandating the use of 4 billion gallons of renewable fuels in the U.S. starting in 2006, increasing to 7.5 billion gallons by the year 2012. Other key provisions of the Energy Policy Act of 2005 (EPACT 2005) included elimination of the minimum 2.0 weight percent oxygen requirement in RFG, establishment of a credits trading program, consolidation of VOC Control Regions, establishment of small refiner provisions, modifications to the mobile source air toxics program and baselines, commingling of compliant RFG fuels, and other fuel related provisions.

4.2.1.2 In response to EPACT 2005, EPA conducted a rulemaking to eliminate the minimum oxygen content requirement for RFG both nationally and in California. The rule eliminating the oxygen content requirement for Federal RFG areas in California became effective April 24, 2006. The rule eliminating the oxygen requirement for all other RFG areas became effective May 5, 2006.

4.2.1.3 For 2006, EPA adopted the default renewable fuel standard set forth in EPACT 2005. The final rule establishing the complete RFS program for 2007 and beyond became effective September 1, 2007. The Rule established annual renewable fuel standards through 2012, defined the responsibilities of refiners and other fuel producers and importers, established a credit trading system and set forth recordkeeping and reporting requirements. Under the RFS regulations, any party that produces or imports gasoline for use in the U.S. is considered an obligated party and is required to meet the annual renewable fuel standard through the purchase of renewable identification numbers (RINs). Qualifying small refiners and small refineries are exempt from meeting

the renewable fuel requirements through 2010. Gasoline producers located in Alaska, and noncontiguous U.S. territories are exempt from the RFS program indefinitely- however these states and territories may opt into the program. Hawaii opted into the program as of January 1, 2008.

4.2.1.4 The Energy Independence and Security Act of 2007 (P.L. 110-140), enacted on December 19, 2007, significantly expands and increases the Renewable Fuel Standard established under the Energy Policy Act of 2005. Section 202 of the Energy Independence and Security Act of 2007 (EISA) required the use of 9.0 billion gallons of renewable fuel in 2008, increasing to 36 billion gallons by 2022. In 2022, 21 billion gallons of the total renewable fuels requirement must be obtained from cellulosic ethanol and other advanced biofuels. Table 2 shows the applicable volumes of total renewable fuels required under the Energy Independence and Security Act of 2007.

4.2.1.5 On November 27, 2007, EPA issued a direct final rule announcing that the 2008 renewable fuel standard would be 4.66 percent. In response to EISA 2007, EPA published a revised 2008 standard of 7.76 percent on February 14, 2008. This standard corresponded to the 9.0 billion gallon target volume for 2008 mandated in EISA 2007.

4.2.1.6 The Energy Independence and Security Act of 2007 establishes annual standards for four categories of renewable fuel – cellulosic biofuel, biomass-based diesel, total advanced biofuel, and total renewable fuel. To qualify under any of these categories, a renewable fuel must meet a certain lifecycle greenhouse gas emission threshold, unless the fuel is produced in a facility that had commenced construction prior to enactment of the legislation. EPA is charged with issuing regulations to implement the provisions of EISA 2007. The new regulations will address how the four standards will be set and how obligated parties will comply with the four standards in addition to other detailed provisions of the legislation.

4.2.2 The Federal Register provides the legal requirements for federal reformulated gasoline. The EPA Office of Transportation and Air Quality publishes notices from the Federal Register on the following internet site: <http://www.epa.gov/fedrgstr/>

4.2.3 Covered areas include those areas required under the Clean Air Act Amendments of 1990 and opt-in areas. A list of areas required to use reformulated gasoline is published on EPA's web page at <http://www.epa.gov/otaq/rfg.htm>. Contact the EPA for the most current list of covered areas.

Table 2

ENERGY INDEPENDENCE AND SECURITY ACT OF 2007 (P.L. 110-140)

Schedule of Renewable Content of Fuel

Calendar Year	Applicable Volume of Renewable Fuel (Billions of Gallons)
2006	4.0
2007	4.7
2008	9.0
2009	11.1
2010	12.95
2011	13.95
2012	15.2
2013	16.55
2014	18.15
2015	20.5
2016	22.25
2017	24.0
2018	26.0
2019	28.0
2020	30.0
2021	33.0
2022	36.0

4.2.4 All areas that choose or are required to use RFG after the year 2000 must implement the more stringent Phase II standards. Areas that chose to use RFG in their air quality plans and did not opt-out by December 31, 1997, were required to participate in Phase II RFG until December 31, 1999.²

4.2.5 Refiners were required to use the Complex Model starting January 1, 1998. Compliance with the Phase II performance standards began January 1, 2000.

4.2.6 Table 1 shows Phase II Complex Model standards. There are both performance standards (VOCs, NO_x, toxics) and content standards (oxygen, benzene). The standards are more stringent if the

refiner elects to meet them on an averaging, rather than per-gallon basis.

4.2.7 The complex model is used to calculate NO_x, toxics, and VOC emissions reductions for reformulated gasoline. For calculating emissions reductions from 1998 on, the baseline gasoline shall be set equal to the Clean Air Act statutory baseline for the summer (VOC control period) or EPA specifications for winter (non-VOC control period) baseline gasolines (Table 3). Refiners must comply with both RFG toxics performance standards and EPA's Mobile Source Air Toxics (MSAT) standards. The EPA MSAT rule published February 26, 2007, limits the benzene content of gasoline to an annual

² Final Rule on Transitional and General Opt-Out Procedures for Phase II Reformulated Gasoline, Federal Register, Vol. 62, October 20, 1997, p. 54552

Table 3

EPA BASELINE FUEL COMPOSITIONS

Fuel Property	VOC control period	Non-VOC control period
Oxygen, mass %	0.0	0.0
Sulfur, ppm, (m/m)	339	338
Vapor Pressure (RVP), kPa (psi)	60.0 (8.7)	79.3 (11.5) ^A
E200, vol. %	41.0	50.0
E300, vol. %	83.0	83.0
Benzene, vol%	1.53	1.64
Aromatics, vol. %	32.0	26.4
Olefins, vol. %	9.2	11.9

^A 60 kPa (8.7 psi) is used for non-VOC control period calculations.

average of 0.62 vol. % beginning in 2011, and the maximum average benzene level to 1.3 vol. % beginning in 2012. The rule includes a nationwide averaging, banking, and trading program. The refinery-specific baselines applicable under the MSAT rule of 2000 were based on 1998-2000 averages. EPA allows refiners and importers of conventional gasoline produced or imported for use in Hawaii, Alaska, Puerto Rico, and the U.S. Virgin Islands to petition EPA to change the way in which they calculate emissions from such gasoline.³

4.2.8 The complex model is used to calculate NOx and exhaust toxics emissions for conventional gasoline (to meet anti-dumping requirements). Refiners' baseline volumes, properties and emissions performance are used to determine refiners' emission requirements. Conventional gasoline must also comply with MSAT standards.

4.2.9 The Complex Model is comprised of seven exhaust emissions equations (for VOCs, NOx, and five toxics: benzene, 1,3-butadiene, formaldehyde,

acetaldehyde and polycyclic organic matter (POM)). Exhaust emissions are expressed as the sum of exponential functions of gasoline properties for two types of vehicles, normal and high emitters. The model also comprises four non-exhaust emission equations for VOCs (diurnal, hot soak, running loss and refueling emissions) and four corresponding non-exhaust emission equations for benzene. Non-exhaust VOC emissions are a function of vapor pressure (RVP) and (RVP)². Non-exhaust benzene emissions are a function of [benzene x non-exhaust VOCs] x [a + b(MTBE) + c(RVP)]. The equations for exhaust formaldehyde and acetaldehyde and for non-exhaust benzene are oxygenate-specific.

4.2.10 For VOC control period gasoline, the full set of equations applies. For non-VOC control period gasoline, non-exhaust emissions are set equal to zero. There are separate versions of the non-exhaust equations for EPA Control Regions 1 and 2.

4.2.11 Table 4 summarizes the terms in the exhaust and non-exhaust equations.

³ EPA Final Rule: Modification of Baselines for Gasoline Produced or Imported for Use in Hawaii, Alaska and U.S. Territories, Federal Register, Vol. 72, No. 206, October 25, 2007, pages 60570-60583.

Note: Throughout this research report, the term "RVP" is used by the EPA to mean vapor pressure, even though D 323 is not the test method used for measurement, and the measurement is therefore not a true Reid Vapor Pressure. Refer to Section 6, Test Methods.

Table 4

EPA MODEL TERMS INCLUDED IN COMPLEX MODEL

Model Terms	Exhaust			Non-Exhaust	
	VOCs	NOx	Toxics ^A	VOCs	Benzene
Vapor pressure (RVP)	X	X	X	X	X
(RVP) ²				X	X
(RVP) ³					X
Oxygen	X	X	X		
Aromatics	X	X	X		
(Aromatics) ²		X			
Benzene			X		X
Olefins	X	X	X		
(Olefins) ²		X			
Sulfur	X	X	X		
(Sulfur) ²		X			
E200	X	X	X		
(E200) ²	X				
E300	X	X	X		
(E300) ²	X				
Aromatics x E300	X				
MTBE			X		X
TAME					
ETBE			X		
Ethanol			X		

More complex oxygenates are handled differently; refer to the Federal Register, Vol. 59, No. 132, 2/16/94, pgs. 7817, 7825, and the 7/20/94 Direct Final Rule.

^A Does not include Polycyclic Organic Matter.

4.2.12 The Complex Model shall be used over the ranges for gasoline properties shown in Table 5. However, within these ranges there are limits for certain gasoline properties: E200, E300, and aromatics for the VOC exhaust equation and sulfur, aromatics, and olefins for the NOx equation. Below and above these ranges the Complex Model extrapolates, either using the value of the derivative (i.e., the slope, in the case of a straight line) of the equation at the limit or making a flat line extension. The Complex Model standards applicable to conventional gasoline require that annual averages of

each complex model parameter shall not be greater than the model valid range limits or the refiner or importer's annual 1990 baseline for that parameter, whichever is greater. An individual batch of conventional gasoline may have parameters that exceed the complex model acceptable range limits. EPA regulations provide a procedure for evaluating the emissions performance of conventional gasoline with parameters outside of the complex model valid range limits.⁴

⁴ Final Rule on Modifications to Standards and Requirements for Reformulated and Conventional Gasoline, Federal Register, Vol. 62, December 31, 1997, p. 68196.

Table 5

EPA VALID RANGES FOR COMPLEX MODEL

Property	RFG		Conventional	
	Low	High	Low	High
Vapor pressure, kPa (psi)	44.1 (6.4)	69.0 (10.0)	44.1 (6.4)	75.8 (11.0)
Oxygen ^A , mass %	0.0	4.0	0.0	4.0
Aromatics, vol%	0.0 ^B	50.0	0.0 ^B	55.0
Olefins, vol. %	0.0	25.0	0.0	30.0
Benzene, vol. %	0.0	2.0	0.0	4.9
Sulfur, ppm m/m	0.0	500.0	0.0	1,000.0
E200, vol. %	30.0	70.0	30.0	70.0
E300, vol. %	70.0	100.0 ^C	70.0	100.0 ^C

^A Pertains to all oxygenates.

^B If <10 vol. %, set equal to 10 vol. %.

^C If >95 vol. %, set equal to 95 vol. %.

4.2.13 A spreadsheet of the Complex Model may be obtained from EPA's Office of Transportation and Air Quality web page under "RFG Computer Models" at <http://www.epa.gov/otaq/rfg.htm>. The Complex Model spreadsheet is a tool but is not part of the regulation. The written text of the regulation as printed in the Federal Register (and as modified by subsequent Federal Register notices) shall be used for certification.

4.2.14 The federal regulations allow for augmentation of the exhaust emissions part of the Complex Model by vehicle testing (CFR 40, Part 80, Section 48) if a fuel claims emission reduction benefits from fuel parameters that are not included in the model or its database, or if the values of the fuel parameters are outside the valid ranges for the model.

4.2.15 Except for some fuel specific certifications, the fuel shall contain a deposit control additive to minimize deposits in fuel injectors and on intake valves. The additive shall comply with EPA 40 CFR 80 Regulation of Fuel and Fuel Additives: Deposit Control Gasoline Additives. The regulations require that the additive limit PFI performance degradation to a maximum flow loss of 5% in any injector and limit the amount of intake valve deposit, averaged over all valves, to less than 100 mg after 10,000 miles of testing.

4.3 California Phase 2 Reformulated Gasoline (CaRFG2) [Expired]

4.3.1 All spark-ignition engine fuel produced between March 1, 1996 and December 30, 2003 for sale in California was required to comply with California Phase 2 Reformulated Gasoline (CaRFG2) regulations. [See Appendix X6 for additional information on CaRFG2.]

4.4 California Phase 3 Reformulated Gasoline (CaRFG3)

4.4.1 The California Air Resources Board (CARB) adopted California Phase 3 Reformulated Gasoline Regulations (CaRFG3) in a hearing on December 9, 1999 with a compliance date beginning December 31, 2002. In a hearing on July 25, 2002, the compliance date was postponed until December 31, 2003. In addition to CaRFG2 requirements, CaRFG3 regulations prohibit the use of methyl tertiary-butyl ether (MTBE) in gasoline starting December 31, 2003, establish CaRFG3 standards, establish a new Phase 3 Predictive Model that includes an evaporative emissions element and CO credit mechanism, and makes amendments to other provisions of the CaRFG2 regulations. The CaRFG3 regulations also included provisions allowing refiners to produce gasoline subject to the CaRFG3 standards prior to December 31, 2003. Table 6 summarizes CaRFG3 standards.

4.4.2 The CARB adopted Follow-Up Amendments to the CaRFG3 Regulations in a hearing on November 16, 2000. The amendments became effective on August 20, 2001 when they were filed with the Secretary of State. The follow-up amendments establish specifications for denatured ethanol intended for blending into gasoline, a California RBOB (CARBOB) model and downstream CARBOB cap limits, make certain changes regarding blending ethanol into gasoline, and establish a mechanism for a small refiner to offset excess emissions from small refiner CaRFG3. CARB also adopted amendments to the test methods designated for determining the olefin content and distillation temperatures of gasoline in a hearing on November 16, 2000. The test method amendments became effective on September 27, 2001 when they were filed with the Secretary of State. CARB adopted amendments to the CaRFG3 Regulations in a hearing on June 14, 2007 and became effective on August 29, 2008 when they were filed with the Secretary of State. These amendments include updating the Phase 3 Predictive Model with information made available to CARB since 1999, adding a sulfur content cap limit of 20 ppm (the updated model and the new sulfur limit are required beginning December 31, 2009), updating the test method for oxygen from ASTM D4815-99 to ASTM D4815-04, and changing the maximum denaturant content limit for ethanol from 4.76% to 5.00% to be consistent with ASTM D4806-06c.

4.4.3 General requirements for CaRFG, including deposit control additives and the elimination of lead, were implemented in 1992. Prohibition of manganese and the limitation of the phosphorus content in California unleaded gasoline occurred in 1977. The regulations appear in the California Code of Regulations, Title 13, sections 2250 - 2272.

4.4.4 CARB adopted amendments to the Gasoline Deposit Control Additive Regulation (Section 2257, Title 13, CCR) in a hearing on September 24, 1998. The amendments became effective on July 16, 1999. Under the revised regulation, CARB requires that a gasoline formulation (i) must meet an intake valve performance standard of 50 milligrams per valve averaged across all four intake valves, (ii) does not result in a flow loss of more than five percent for any

fuel injector, and (iii) requires a new performance standard that combustion chamber deposits not exceed 1300 milligrams total deposit weight, when averaged over all four combustion chambers, or, does not result in more than 140 percent total deposit weight from all four combustion chambers, relative to the gasoline formulation containing no additive.

4.4.5 The CaRFG specifications address eight different fuel properties. The CaRFG regulations, which overall are more restrictive than those adopted by the U. S. EPA for federal reformulated gasoline; allow producers the option of meeting flat limits or averaging limits. Averaging is permitted for all properties other than oxygen content and vapor pressure. The averaging limits are numerically more stringent than comparable flat limits. CaRFG regulations also contain caps, which are absolute and shall not be exceeded by any gallon of California reformulated gasoline. Under 40 CFR 80.81, "Enforcement Exemptions for California Gasoline", U.S. EPA exempts refiners, importers, and blenders of gasoline subject to the state of California's Phase 3 reformulated gasoline regulations from certain enforcement provisions in the federal reformulated gasoline regulations such as recordkeeping and reporting, and certain sampling and testing requirements.

4.4.6 CARB established a primary statewide oxygen range for RFG of 1.8 - 2.2 mass% for gasoline. Alternately, producers may use the California Predictive Model (see 4.4.8) to sell gasoline with an oxygen content between 0 and 3.5 mass%. During the winter months, gasoline sold or supplied in the South Coast Area (which includes the counties of Los Angeles, Orange, Riverside, San Bernadino, and Ventura) and Imperial County is required to meet a minimum of 1.8 mass%. Under the Energy Policy Act of 2005, EPA issued a rule eliminating the minimum oxygen content requirement for Federal RFG areas in California that prohibited the sale of gasoline containing less than 2.0 mass% oxygen content (1.5% averaging minimum). The Rule was effective April 24, 2006.

4.4.7 CARB regulations limit vapor pressure statewide to 48.3 kPa (7.00 psi), during the summer control season, which is longer than the EPA control season. Table 7 lists the air basins, the regulatory control periods, and the regulatory control periods for gasoline producers and importers.

Table 6

CARB PHASE 3 REFORMULATED GASOLINE REGULATIONS
CaRFG3 Average and Flat Limits with Per Gallon Maximums and Minimums

Regulated Property	CARB Phase 3 (December 31, 2003 +)		
	Flat Limit	Averaging Limit	Max. Per Gallon Cap
Aromatics, max, vol. %	25.0	22.0	35.0
Benzene, max, vol. %	0.80	0.70	1.10
Olefins, max, vol. %	6.0	4.0	10.0
Oxygen, mass %	1.8 - 2.2	Not Applicable	1.8 - 3.5 ^A winter areas
			0 - 3.5 ^A
Vapor Pressure, max, kPa (psi) during the RVP Control Period	48.3 or 47.6 (7.00 or 6.90 w/evap PM) ^B	Not Applicable	44.1-49.6 (6.40 - 7.20)
Distillation Temperature, max, °C (°F), at % evaporated	213	203	220
			330
Sulfur, max, ppm (m/m)	20	15	60 ^C
			30 ^C
			20 ^C
MTBE and oxygenates other than ethanol, vol. %	Prohibited as provided in Section 2262.6 ^D	Not Applicable	Prohibited as provided in Section 2262.6 ^D

^A If the gasoline contains more than 3.5% by weight oxygen but no more than 10 volume % ethanol, the maximum oxygen content cap is 3.7% by weight.

^B The 6.90 psi flat limit applies only when a producer or importer is using the evaporative emissions model element of the CaRFG Phase 3 Predictive Model, in which case all predictions for evaporative emissions increases or decreases made using the evaporative emissions model are made relative to 6.90 psi and the gasoline may not exceed the maximum RVP cap limit of 7.2 psi. Where the evaporative emissions model element of the CaRFG Phase 3 Predictive Model is not used, the RVP of gasoline sold or supplied from the production or import facility may not exceed 7.0 psi. The 6.90 psi flat limit applies **only** when a producer or importer is using the CaRFG Phase 3 Predictive Model to certify a final blend not containing ethanol. Otherwise, the 7.00 limit applies.

^C The CaRFG Phase 3 sulfur content cap limits of 60, and 30, and 20 parts per million are phased in starting December 31, 2003 and December 31, 2005, and December 31, 2011 respectively.

^D Starting December 31, 2003, no person shall use MTBE, in neat form, in the production of California gasoline; or a blending component that contains greater than 0.60 volume percent MTBE when supplied to its California production facility in the production of California gasoline. MTBE concentrations may not exceed 0.60 volume percent beginning December 31, 2003, 0.30 volume percent beginning July 1, 2004, 0.15 volume percent beginning December 31, 2005; and 0.05 volume percent beginning July 1, 2007. In addition, total oxygenates, other than ethanol and MTBE, may not exceed 0.10 weight percent oxygen beginning December 31, 2003 and 0.06 weight percent beginning July 1, 2004. The California Reformulated Gasoline Phase 3 Amendments, Title 13, California Code of Regulations, Section 2262.6

Table 7

**CARB PHASE 3 REFORMULATED GASOLINE REGULATIONS
RVP Control Periods in California**

Air Basin	Regulatory Control Period	Regulatory Control Period (Producers & Importers)
South Coast and Ventura County	April 1 - October 31	March 1 - October 31
San Diego	April 1 - October 31	March 1 - October 31
Mojave Desert	April 1 - October 31	March 1 - October 31
Salton Sea	April 1 - October 31	March 1 - October 31
Great Basin Valley	May 1 - September 30	April 1 - September 30
San Francisco Bay Area	May 1 - October 31	April 1 - October 31
San Joaquin Valley	May 1 - October 31	April 1 - October 31
Sacramento Valley	May 1 - October 31	April 1 - October 31
Mountain Counties	May 1 - October 31	April 1 - October 31
Lake Tahoe	May 1 - October 31	April 1 - October 31
North Coast	June 1 - September 30	May 1 - September 30
Lake County	June 1 - September 30	May 1 - September 30
Northeast Plateau	June 1 - September 30	May 1 - September 30
North Central Coast	June 1 - October 31	May 1 - September 30
South Central Coast ex. Ventura Co	June 1 - October 31	May 1 - October 31

^A RVP control periods were amended by CARB on August 27, 1998 and became effective September 21, 1998.

4.4.8 Producers in California can use the California Predictive Model to establish specifications for an alternative gasoline formulation in lieu of meeting the CaRFG specifications. Through the use of the Predictive Model, producers shall show that an alternative formulation would result in emissions reductions equivalent to or better than a fuel meeting the CaRFG3 specifications.

4.4.9 The California Predictive Model is a set of equations which determine the change in exhaust hydrocarbon emissions, exhaust emissions of oxides of nitrogen, the combined emissions of four toxic air contaminants (1,3-butadiene, benzene, formaldehyde and acetaldehyde), and includes an evaporative

emissions element and CO credit mechanism. Table 8 describes the model terms included in the exhaust predictive model for CaRFG3. Table 9 describes the model terms included in the evaporative predictive model for CaRFG3.

4.4.10 The CaRFG3 regulations also allow for an alternative CaRFG3 formulation if it can be shown through the vehicle testing option ("California Test Procedure for Alternative Specifications for Gasoline", section 2266, Title 13 California Code of Regulations) that emissions resulting from the use of the alternative formulation are equal to or less than emissions resulting from the use of CaRFG3 Gasoline.

Table 8

**CARB PHASE 3 CALIFORNIA PREDICTIVE MODEL
Exhaust Terms Included in the CaRFG3 Model**

Model Terms	Exhaust			
	Total Hydrocarbons	NOx	Toxics ^A	CO
Vapor Pressure	X	X	X	X
Oxygen	X	X	X	X
(Oxygen) ²		X		X
Oxygen x T90	X			
Aromatics	X	X	X	X
(Aromatics) ²	X			
Aromatics x T90	X	X		
Aromatics x Oxygen	X			
Benzene			X	
Olefins	X	X	X	X
Sulfur	X	X	X	X
T50	X	X	X	X
(T50) ²	X	X		
T50 x T90				X
T90	X	X	X	X
(T90) ²	X			X
T50 x Aromatics	X			X
T50 x Oxygen	X	X		X
T90 x Olefins	X			X

^A Toxics are potency weighted.

Table 9

**CARB PHASE 3 CALIFORNIA PREDICTIVE MODEL
Evaporative Terms Included in the CaRFG3 Model**

Model Terms	Evaporative					
	Hydrocarbons			Benzene		
	Running Loss	Hot Soak	Diurnal	Running Loss	Hot Soak	Diurnal
Vapor Pressure	X	X	X	X	X	X
(Vapor Pressure) ²	X	X		X	X	
Benzene				X	X	X
Benzene x Vapor Pressure				X	X	X
MTBE x Benzene					X	
Ethanol	X	X	X	X	X	X

5. EPA Gasoline Sulfur Standards

5.1 EPA Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements

5.2 On December 21, 1999, EPA issued a Notice of Final Rulemaking: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements. The Final Rule was published in the Federal Register on February 10, 2000. Gasoline sulfur standards apply to refineries and importers producing reformulated, RBOB, or conventional gasoline. For purposes of the regulation, a "refinery" is "any facility, including but not limited to, a plant, tanker truck, or vessel where gasoline is produced, including any facility at which blendstocks are combined to produce gasoline, or at which blendstock is added to gasoline". EPA sulfur regulations allow a refiner or importer to include oxygenate when calculating sulfur content, provided certain conditions are met. For conventional gasoline, the requirements of 40 CFR § 80.101(d)(4)ii must be met. For reformulated gasoline, the requirements of § 80.69(a) must be met.

5.3 Table 10 summarizes gasoline sulfur content standards for refiners and importers. The regulation requires that in 2004, refiners are required to meet an

annual corporate average sulfur level of 120 parts per million (ppm), with a cap of 300 ppm. In 2005, the required refinery average is 30 ppm, with a corporate average of 90 ppm and a cap of 300 ppm. Both of the average standards can be met with the use of credits generated by other refiners who reduce sulfur levels early. In 2006, refineries are required to meet a final 30 ppm average with a cap of 80 ppm.

5.4 Gasoline produced for sale in parts of the western United States must comply with a 150 ppm refinery average and a 300 ppm cap through 2006, but will be required to meet the 30 ppm average/80 ppm cap by 2007. Refiners demonstrating a severe economic hardship may apply for an extension of up to two years. The regulations include an averaging program.

5.5 Refiners approved by the Environmental Protection Agency as qualifying for small refiner status are allowed to meet less stringent standards through December 31, 2007. Small refiners are defined as employing no more than 1,500 employees and having a capacity not exceeding 155,000 barrels per day. Table 11 summarizes gasoline sulfur standards for approved small refiners.

Table 10

EPA GASOLINE SULFUR STANDARDS FOR REFINERS AND IMPORTERS ^A

	Gasoline Sulfur Standards (Tier 2) for the averaging period beginning:			
	January 1, 2004	January 1, 2005	January 1, 2006	January 1, 2007 & subsequent years
Basic Federal Program				
Refinery or Importer Average	Not Applicable	30.00	30.00	30.00
Corporate Pool Average	120.00	90.00	Not Applicable	Not Applicable
Per-Gallon Cap	300	300	80	80
Geographical Phase-in Program (GPA) - North Dakota, Montana, Idaho, Wyoming, Utah, Colorado, New Mexico, and Alaska ^{B, C}				
Refinery Average	150	150	150	30
Corporate Pool Average ^D	120	90	Not Applicable	Not Applicable
Per-Gallon Cap	300	300	300	80

^A EPA Final Rule, Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Federal Register: February 10, 2000, Vol.65, No. 28, February 10, 2000, pages 6697-6870.

^B Under 40 CFR 80.215(a)(1) and (2), certain counties and tribal lands were also included in the GPA.

^C Under 40 CFR 80.540, an extension of the January 1, 2006 GPA sulfur limits is available to EPA approved GPA refineries that applied to EPA by December 31, 2001 and produced 15 ppm diesel fuel beginning June 1, 2006. This extension is in effect through December 31, 2008 at the refinery level and through February 28, 2009 at the retail level.

^D A refiner or importer whose gasoline production or volume of imported gasoline in 2004 or 2005 was comprised of more than 50 percent of gasoline designated as GPA gasoline under 40 CFR 80.219(a) was not required to meet the corporate pool average standards under 40 CFR 80.195 for its gasoline production or imported gasoline during the applicable averaging period.

Table 11

EPA GASOLINE SULFUR STANDARDS FOR SMALL REFINERS^A

Refinery Baseline Sulfur Level	Temporary Sulfur Standards Applicable from January 1, 2004 through December 31, 2007	
	Annual Average	Per Gallon Cap
0 to 30	30.00	300
31 to 200	Baseline level	300
201 to 400	200.00	300
401 to 600	50% of baseline	Factor of 1.5 times the average standard
601 and above	300.00	450

^A EPA Final Rule, Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Federal Register: February 10, 2000, Vol.65, No. 28, February 10, 2000, pages 6697-6870.

6. Test Methods

6.1 The specified fuel properties shall be determined in accordance with the test methods listed below.

Table 12

Summary of ASTM, EPA, and CARB Test Methods and EPA Enforcement Tolerances and CARB Reproducibilities for Reformulated Gasoline

PROPERTY	ASTM ^A		EPA		CARB	
	Test Method	Comments/Limitations	Test Method	Enforcement Tolerance ^B	Test Method	Reproducibility of CARB Method
Aromatics	D1319-08	Correct for oxygenate measured by D4815 or D5599 or equivalent	ASTM D5769-04, (except sample chilling requirements in Table 8 are optional)	N/A	D5580-00	1.4 v%
	D5580-02 (2007)	None	D1319-03 ^{e1} if correlated with ASTM D5769-04	N/A		
	D5769-04	None				
Benzene	D3606-07	Alcohol interferes	D3606-07 with exceptions for methanol and ethanol ^C	0.21 v%	D5580-00	0.1409(x) ^{1.133} v%
	D4053-04 (2009)	None				
	D5580-02 (2007)	None				
	D5769-04	None				
	D5986-96 (2006)	None				
Distillation	D86-09 ^{e1}	None	D86-07b	N/A	D86-99a ^{e1}	Variable as a function of slope
Olefins	D1319-08	Correct for oxygenate measured by D 4815 or D 5599 or equivalent	D1319-03 ^{e1}	N/A	D6550-00 ^{D,E}	CARB uses 0.32(x) ^{0.5} ; where x is between 0.3 and 25 mass% olefin
	D1159-07	None				
Oxygen	D4815-04	None	D4815-04 if correlated with ASTM D5599-00 (2005)	0.3 w%	D4815-04	For MTBE: 0.12 (x) ^{0.67} m% For ETOH: 0.23 (x) ^{0.57} m% Other oxygenates have other equations
	D5599-00 (2005)	None	ASTM D5599-00 (2005)			
	D5622-95 (2005)	None			Equiv.:GC/FTIR ^E	For MTBE range: 1 to 15 m% 0.17 (x) ^{0.5} m% For Ethanol range 1 to 12 m% 0.11 (x) ^{0.5} m%
	D5845-01 (2006)	None				

PROPERTY	ASTM ^A		EPA		CARB	
	Test Method	Comments/Limitations	Test Method	Enforcement Tolerance ^B	Test Method	Reproducibility of CARB Method
Sulfur	D3120-08	Range: 3.0 to 1000 mg/kg	D2622-05	Downstream Standards ^F See Case II reproducibility equation of ASTM D 2622-98	Range: > 10 ppm D2622-94 with low S calibration.	For range: 10 to 30 ppm 0.405(x) ppm For range: >30 ppm 0.192(x) ppm
	D2622-08	Range: 3 mg/kg to 4.6 mass %	D5453 -08a if correlated with D2622-05		Range: > 10 ppm D5453-93	0.2217(x) ^{0.92} ppm
	D4045-04	Range: 0.02 to 10.00 mg/kg	D6920 -07 if correlated with D2622-05		Range: 1 to 10 ppm D5453-93	0.2217(x) ^{0.92} ppm
	D4294-08a	Range: 17 mg/kg to 4.6 mass %	D3120 -06 ^{E1} if correlated with D 2622-05		Range: 1 to 10 ppm. Equiv.: D4045-92 (modified) ^E	0.26 (x) ^{0.5} ppm
	D5453-09	Range: 1 to 8000 mg/kg	D7039 -07 if correlated with D 2622-05		Range: 1 to 10 ppm Equiv.: D 4045-96 ^E	0.26 (x) ^{0.5} ppm
	D6920-07	Range: 1 to 100 mg/kg			Range: 2 to 100 ppm Equiv.: D7039-04 ^E	0.4761(x) ^{0.500} ppm
	D7039-07	Range: 2 to 500 mg/kg				
Vapor Pressure	D4953-06	Method A = dry bomb Method B = Herzog (with B@A correlation equations)	ASTM D5191 -07 except that the following correlation must be used: RVP psi = (0.956*X)-0.347 RVP kPa = (0.956*X)-2.39 Where: X=total measured vapor pressure in psi or kPa	0.30 psi ^G	D 323-58	0.30 psi
	D5190-07	None			Section 2297 in Title 13 of the California Code of Regulations	0.21 psi
	D5191-07	None			Range: up to 9.50 psi Equiv.: D6378-08 using the relative bias for CARB ^{E,H}	0.0273 (x + 1.31) psi
	D5482-07	None				
	D6378-08	None				
Detergency (PFI)	D5598-01 (2007)	Vehicle evaluation	D5598-94	N/A	D5598-95a	N/A
Detergency (IVD)	D5500-98 (2008)	Vehicle evaluation	D5500-94	N/A	D5500-98	N/A
Detergency (CCD)	N/A	N/A	N/A	N/A	Stationary Source Division's Test Method for Evaluating Intake and Combustion Chamber Deposits in Vehicle Engines	N/A

^A For ASTM reproducibility and repeatability refer to most recent version of "Annual Book of ASTM Standards".

^B EPA enforcement tolerances apply downstream of the refinery, and apply only to those properties governed by downstream minimum or maximum standards.

^C Under EPA's Regulations in CFR 80.46(e)(2), instrument parameters shall be adjusted to ensure complete resolution of the benzene, ethanol, and methanol peaks to overcome possible alcohol interference.

^D For D6500-00, the application range applied by CARB is 0.3 to 25 mass%. The conversion from mass% olefin to volume% olefin is: volume% olefin = (0.857) (mass% olefin).

^E Deemed equivalent by CARB.

^F Under EPA's Final Rule on Tier 2/Sulfur Requirements, EPA established "downstream standards" based on the Case II reproducibility equation of ASTM D 2622-98. The downstream standards for sulfur are intended to provide the same effect as

enforcement tolerances in other EPA programs and apply to alternative and designated EPA test methods for sulfur. Final Rule, Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements, Federal Register: February 10, 2000, Vol. 65, No. 28, pages 6697-6870.

^G Enforcement tolerance for RVP applies only to Phase I RFG and conventional gasoline. Under Phase II RFG, EPA provides an enforcement tolerance of 2% for VOC controlled gasoline. [See Table 1, "EPA Complex Model Standards for Federal RFG"].

^H The relative bias for CARB is listed in Note 18 of ASTM D6378-08. For predicting CARB RVPE, use the following equation
$$\text{CARB RVPE} = \text{VP}_4(37.8^\circ\text{C})_{1\text{-L container}} - \text{Relative Bias}.$$

APPENDICES

(Nonmandatory Information)

X1. SIGNIFICANCE OF SPECIFIED PROPERTIES FOR REFORMULATED SPARK-IGNITION ENGINE FUEL

X1.1 General

X1.1.1 The characteristics of reformulated fuel described in this Research Report are legal requirements which are imposed by the U. S. EPA, under the authority of the 1990 Clean Air Act Amendments (CAAA), and the California Air Resources Board's Phase 2 and Phase 3 Reformulated Gasoline Regulations, to lower the exhaust and evaporative emissions from automotive vehicles. Aromatics, benzene, olefins, oxygen/oxygenates, vapor pressure, sulfur and E200/300 percentages (distillation) are controlled variables in the federal Complex Model and the California Predictive Model. The significance of these fuel characteristics is described below.

X1.1.2 Exhaust and evaporative emissions from spark-ignition automotive vehicles are affected by the composition and volatility of the fuel. Hydrocarbon and oxygenated hydrocarbon emissions that escape into the atmosphere are called Volatile Organic Compounds (VOCs). These emissions occur as tank storage losses, refueling losses, or as exhaust emissions or evaporative losses that occur either during vehicle operation or when the vehicle is at rest. Volatile Organic Compounds (VOCs), when emitted into the atmosphere, contribute to the photochemical formation of ozone, a major air quality problem in many urban areas.

X1.1.3 Exhaust and evaporative emissions from spark-ignition automotive vehicles may also contain the regulated air toxics defined in the 1990 CAAA: benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and/or polycyclic organic matter. The amount of these toxics present in automotive emissions can be affected by the composition of the fuel.

X1.1.4 Other fuel characteristics affecting engine operability, which are outside the scope of these reformulated fuel regulatory controls, are found in ASTM D 4814, Standard Specification for Automotive Spark-Ignition Engine Fuel. These operability characteristics are not discussed in this Research Report.

X1.2 Aromatics

X1.2.1 Aromatic compounds are unsaturated ring-structured compounds controlled by EPA and CARB regulations because they contribute to VOC and toxics inventories.

X1.3 Benzene

X1.3.1 Benzene is controlled in reformulated gasoline because it is a toxic chemical. A portion of the fuel benzene may pass through the engine unburned, and benzene may be produced in the engine from precursors present in the fuel, adding to the total benzene present in the engine exhaust and evaporative emissions.

X1.4 Olefins

X1.4.1 Olefins are chemically reactive unsaturated straight or branched chain hydrocarbons which are controlled variables in the federal Complex Model and the CARB Predictive Model. In the Complex Model, olefins affect exhaust VOC, NOx and toxics.

X1.5 Oxygen and Oxygenates

X1.5.1 Oxygen is intentionally introduced into reformulated fuel for spark-ignition engines by the addition of organic, fuel-soluble compounds called oxygenates. These are generally in the form of alcohols or ethers, limited by the Substantially Similar rule and EPA waivers.

X1.5.2 The U.S. Congress, under the Clean Air Act Amendments of 1990, required the addition of oxygen to reformulated fuels to reduce VOC and toxic exhaust emissions. The addition of oxygen to fuel reduces carbon monoxide in exhaust emissions. The Energy Policy Act of 2005 repealed the minimum oxygen content requirement in RFG covered areas. EPA repealed the minimum oxygen content requirement for Federal RFG areas in California effective April 24, 2006. EPA repealed the minimum oxygen content requirement for all other RFG areas effective May 5, 2006.

X1.6 Vapor Pressure

X1.6.1 Although vapor pressure limits are regulated by the EPA for summertime non-reformulated (conventional) spark-ignition engine fuel, EPA and CARB regulations have required further reductions in the vapor pressure of reformulated fuels to reduce VOCs.

X1.6.2 Evaporative losses from automotive fuel systems as well as exhaust emissions are reduced with lower vapor pressure fuel. Lowering the vapor pressure of a fuel also reduces fuel evaporative losses of VOCs to the atmosphere during storage and transfer operations.

X1.7 Sulfur

X1.7.1 Sulfur has been shown to cause a loss of catalyst activity in automotive catalytic converters that is essentially reversible, although loss of activity in some catalysts may not be completely reversible under all operating conditions. Sulfur impacts exhaust emission equations (VOC, NOx) in the federal Complex Model and the California Predictive Model.

X1.8 Distillation Temperature

X1.8.1 Distillation temperature limits on automotive spark-ignition engine fuel are used to control unburned hydrocarbons (VOCs) in the exhaust. The Complex Model controls the distillation of the fuel by controlling the volume percent evaporated at 200°F and at 300°F, while the CARB Predictive Model uses T_{50} (the temperature, in

degrees F, where 50% of the liquid volume of fuel has evaporated) and T_{90} (the temperature, in degrees F, where 90% of the liquid volume of fuel has evaporated), as measured by ASTM D 86.

X1.9 Detergency

X1.9.1 Port Fuel Injector (PFI) - Deposits which form on the metering surfaces of electronic fuel injectors can result in a reduction in fuel flow and disruption of proper fuel air mixing. This results in an imbalance in the air-fuel ratio across the cylinders and in other combustion inefficiencies which can adversely affect emissions, driveability, and fuel economy. The mechanism of deposit formation is not completely understood, but may be influenced by port fuel injector design, engine design, the composition of the fuel used, and by driving cycle. Deposit control additives are required to limit PFI deposits. Additives which are capable of adequately limiting PFI deposits are also accepted as adequately controlling throttle body and carburetor deposits in older vehicles.

X1.9.2 Intake Valve Deposits (IVD) - Deposits which form on the stem and tulip areas of intake valves can adversely affect emissions and driveability. The mechanism of deposit formation is not completely understood, but may be influenced by the composition of the fuel used, engine design, and driving cycle. The mechanism by which intake valve deposits impact emissions is also not completely understood. Adsorption and desorption of fuel on the IVD and the thermal insulating properties of the IVD can interfere with proper air-fuel mixing and the maintenance of proper air-fuel ratio across the cylinders. Deposit control additives are therefore required to limit IVD.

X2. EPA COVERED AREAS

X2.1 Covered Areas are subject to change. Contact the EPA for the most recent list of covered areas.

EPA RFG COVERED AREAS Clean Air Act Required Areas

ATLANTA, GEORGIA¹

- Cherokee County, GA
- Clayton County, GA
- Cobb County, GA
- Coweta County, GA
- DeKalb County, GA
- Douglas County, GA
- Fayette County, GA
- Forsyth County, GA
- Fulton County, GA
- Gwinnett County, GA
- Henry County, GA
- Paulding County, GA
- Rockdale County, GA

LOS ANGELES-South Coast Air Basin, South East Desert, Ventura, CA

- Los Angeles County, CA
- Ventura County, CA
- Orange County, CA
- San Bernardino County (partial), CA
- Riverside County (partial), CA

SAN DIEGO, CA

- San Diego County, CA

HARTFORD-New Haven-Waterbury, CT

- Hartford County (partial), CT
- Litchfield County (partial), CT
- Middlesex County (partial), CT
- New London County (partial), CT
- New Haven County (partial), CT
- Tolland County (partial), CT

PHILADELPHIA-Wilmington-Trenton-Cecil County, MD area PA-NJ-DE-MD

- New Castle County, DE
- Kent County, DE
- Cecil County, MD
- Burlington County, NJ
- Camden County, NJ
- Cumberland County, NJ
- Gloucester County, NJ
- Mercer County, NJ
- Salem County, NJ
- Bucks County, PA
- Chester County, PA
- Delaware County, PA
- Montgomery County, PA
- Philadelphia County, PA

NEW YORK-Northern New Jersey-Long Island-Connecticut area, NY-NJ-CT

- Fairfield County, CT
- Litchfield County (partial), CT
- New Haven County (partial), CT
- Bergen County, NJ
- Essex County, NJ
- Hudson County, NJ
- Hunterdon County, NJ
- Middlesex County, NJ
- Monmouth County, NJ
- Morris County, NJ
- Ocean County, NJ
- Passaic County, NJ
- Somerset County, NJ
- Sussex County, NJ
- Union County, NJ
- Bronx County, NY
- Kings County, NY
- Nassau County, NY
- New York County, NY
- Orange County, NY
- Putnam, NY
- Queens County, NY
- Richmond County, NY
- Rockland County, NY
- Suffolk County, NY
- Westchester County, NY

SACRAMENTO, CA

- El Dorado County (partial), CA
- Placer County (partial), CA
- Sacramento County, CA
- Solano County (partial), CA
- Sutter County (partial), CA
- Yolo County, CA

SAN JOAQUIN VALLEY, CA

- Fresno County, CA
- Kern County (part), CA
- Kings County, CA
- Madera County, CA
- Merced County, CA
- San Joaquin County, CA
- Stanislaus County, CA
- Tulare County, CA

BALTIMORE, MD

- Anne Arundel County, MD
- Baltimore County, MD
- Carroll County, MD
- Harford County, MD
- Howard County, MD
- The City of Baltimore, MD

BATON ROUGE, LOUISIANA²

- Ascension Parish, LA
- East Baton Rouge Parish, LA
- Iberville Parish, LA
- Livingston Parish, LA
- West Baton Rouge Parish, LA

HOUSTON-Galveston-Brazoria, TX

- Brazoria County, TX
- Chambers County, TX
- Fort Bend County, TX
- Galveston County, TX
- Harris County, TX
- Liberty County, TX
- Montgomery County, TX
- Waller County, TX

MILWAUKEE-Racine, WI

- Kenosha County, WI
- Milwaukee County, WI
- Ozaukee County, WI
- Racine County, WI
- Washington County, WI
- Waukesha County, WI

CHICAGO-Gary-Lake County, IL-Indiana-Wisconsin area

- Cook County, IL
- Du Page County, IL
- Kane County, IL
- Lake County, IL
- McHenry County, IL
- Will County, IL
- Grundy County (partial), IL
- Kendall County (partial), IL
- Lake County, IN
- Porter County, IN

¹ Program stayed pending appeal. Originally required to be effective January 1, 2005.

² Program stayed pending EPA reconsideration. Originally required to be effective June 23, 2004.

EPA RFG COVERED AREAS

Opt-In Areas

CONNECTICUT, The Entire State

- Litchfield County (partial), CT
- Hartford County (partial), CT
- Middlesex County (partial), CT
- New London County (partial), CT
- Tolland County (partial), CT
- Windham County, CT

DELAWARE, The Entire State

- Sussex nonattainment area**
- Sussex County, DE

DISTRICT OF COLUMBIA

- Washington, DC-MD-VA area (DC portion)**
- Entire District of Columbia

ILLINOIS

- St. Louis, IL-MO nonattainment area (Illinois portion)**
- Jersey County, IL
- Madison County, IL
- Monroe County, IL
- St. Clair County, IL

KENTUCKY

- Cincinnati-Hamilton KY-OH area (KY portion)**
- Boone County, KY
- Campbell County, KY
- Kenton County, KY
- Louisville, KY-IN area (KY portion)**
- Jefferson County, KY
- Bullitt County (partial), KY
- Oldham County (partial), KY

MARYLAND

- Washington, DC-MD-VA area (MD portion)**
- Calvert County, MD
- Charles County, MD
- Frederick County, MD
- Montgomery County, MD
- Prince Georges County, MD
- Kent & Queen Anne's nonattainment area**
- Queen Anne's County, MD
- Kent County, MD

MISSOURI

- St. Louis nonattainment area**
- Franklin County, MO
- Jefferson County, MO
- St. Charles County, MO
- St. Louis County, MO
- St. Louis City, MO

MASSACHUSETTS, The Entire State **Boston-Lawrence-Worcester (Eastern MA)**

- Barnstable County, MA
- Bristol County, MA
- Dukes County, MA
- Essex County, MA
- Middlesex County, MA
- Nantucket County, MA
- Norfolk County, MA
- Plymouth County, MA
- Suffolk County, MA
- Worcester County, MA
- Springfield (Western MA) nonattainment area**
- Berkshire County, MA
- Franklin County, MA
- Hampden County, MA
- Hampshire County, MA

NEW HAMPSHIRE

- Boston-Lawrence-Worcester, MA-NH nonattainment area (NH portion)**
- Hillsborough County, NH
- Rockingham County, NH
- Merrimack County, NH
- Strafford County, NH

NEW JERSEY, The Entire State

- Allentown-Bethlehem-Easton area (NJ portion)**
- Warren County, NJ
- Atlantic City nonattainment area**
- Atlantic County, NJ
- Cape May County, NJ

NEW YORK

- Essex nonattainment area**
- Dutchess County, NY
- Essex County (partial), NY

RHODE ISLAND, The Entire State

- Providence nonattainment area**
- Bristol County, RI
- Kent County, RI
- Newport County, RI
- Providence County, RI
- Washington County, RI

TEXAS

- Dallas-Fort Worth nonattainment area**
- Collin County, TX
- Dallas County, TX
- Denton County, TX
- Tarrant County, TX

VIRGINIA

Washington DC-MD-VA area (VA portion)

- Alexandria, VA
- Arlington County, VA
- Fairfax, VA
- Fairfax County, VA
- Falls Church, VA
- Loudoun County, VA
- Manassas, VA
- Manassas Park, VA
- Prince William County, VA
- Stafford County, VA

Richmond, VA nonattainment area

- Charles City County, VA
- Chesterfield County, VA
- Colonial Heights, VA
- Hanover County, VA
- Henrico County, VA
- Hopewell, VA
- Richmond, VA

Norfolk-Virginia Beach-Newport News area

- Chesapeake, VA
- Hampton, VA
- James City County, VA
- Newport News, VA
- Norfolk, VA
- Poquoson, VA
- Portsmouth, VA
- Suffolk, VA
- Virginia Beach, VA
- Williamsburg, VA
- York County, VA

EPA RFG COVERED AREAS

Opt-Out Areas

MAINE

Hancock & Waldo Counties

- Hancock County, ME
- Waldo County, ME

Knox & Lincoln nonattainment area

- Knox County, ME
- Lincoln County, ME

Lewiston-Auburn nonattainment area

- Androscoggin County, ME
- Kennebec County, ME

Portland nonattainment area

- Cumberland County, ME
- Sagadahoc County, ME
- York County, ME

NEW YORK

Albany-Schenectady-Troy

- Albany County, NY
- Greene County, NY
- Montgomery County, NY
- Rensselaer County, NY
- Saratoga County, NY
- Schenectady County, NY

Jefferson County, NY

Buffalo-Niagara Falls, NY

- Erie County, NY
- Niagara County, NY

ARIZONA

Phoenix nonattainment area

- Maricopa County (partial), AZ

PENNSYLVANIA

Allentown-Bethlehem-Easton

- Carbon County, PA
- Lehigh County, PA
- Northampton County, PA

Altoona-Blair County

- Erie, PA
- Erie County, PA

Harrisburg-Lebanon-Carlisle

- Cumberland County, PA
- Dauphin County, PA
- Lebanon County, PA
- Perry County, PA

Johnstown

- Cambria County, PA

- Somerset County, PA

Lancaster

- Lancaster County, PA

Pittsburgh-Beaver Valley

- Allegheny County, PA
- Beaver County, PA
- Fayette County, PA
- Washington County, PA
- Westmoreland County, PA
- Armstrong County, PA
- Butler County, PA

Reading

- Berks County, PA

Scranton-Wilkes-Barre

- Columbia County, PA
- Lackawanna County, PA
- Luzerne County, PA
- Monroe County, PA
- Wyoming County, PA

York

- Adams County, PA
- York County, PA

Youngstown-Warren-Sharon

- Mercer, PA

X3. STATE REFORMULATED GASOLINE PROGRAMS

A number of states have adopted regulations requiring cleaner burning gasoline or reformulated gasoline in certain areas of the state. In addition to California, states adopting cleaner burning gasoline standards are Arizona (Maricopa County), Nevada (Clark County), Georgia (Atlanta Area), and Alabama (Jefferson and Shelby Counties). North Carolina has passed legislation regarding reformulated gasoline and sulfur content standards.

This research report covers state reformulated gasoline or cleaner burning gasoline regulations which establish limits on vapor pressure, sulfur, olefins, aromatics, oxygen/oxygenates, and other properties, (and combinations thereof), or have adopted certain provisions of the Federal and/or California reformulated gasoline program. States establishing a lower vapor pressure limit than required by Federal EPA are covered in ASTM D 4814, Standard Specification for Automotive Spark-Ignition Engine Fuel.

X3.1 Arizona CBG

X3.1.1. The State of Arizona requires that all gasoline sold or offered for sale for use in motor vehicles within the Cleaner-Burning Gasoline (CBG) covered area must meet the requirements of Title 20, Chapter 2, Article 7 of the Arizona Administrative

Code. The CBG covered area includes all of Maricopa County and Area A.

X3.1.2 In addition to the other provisions of Article 7, all Arizona CBG must meet the general requirements of Section R20-2-751. (See Table X3.1). Beginning November 1, 2000, a set of wintertime requirements applies. (See Table X3.2). Arizona CBG must also comply with either of the following fuel reformulation options: "Type 1 gasoline", which is similar to Federal Phase II RFG, or "Type 2 gasoline" which is similar to CARB Phase 2 gasoline. (See Table X3.3 for "Type 1 gasoline" and Table X3.4 for "Type 2 gasoline".)

X3.1.3 "Type 1 gasoline" means a gasoline that meets the general requirements of R20-2-751 and the standards contained in Table 1 of Article 7. "Type 2 gasoline", means a gasoline that meets the standards contained in Table 2 of Article 7, or is certified using the California Predictive Model according to the requirements of R20-2-751(F), G, H, and Column A of Table 2 of Article 7.

X3.1.4 In addition to the other requirements of Article 7, from and after November 1, 2000 through March 31, 2001, and from the period beginning November 2 through March 31 of each subsequent year, all Arizona CBG must meet the wintertime requirements provided in Table X3.2.

Table X3.1
ARIZONA CBG
General Requirements

Fuel Property/Performance Standard	Limits
Sulfur (ppm by weight, max)	500
Aromatics (vol. %, max)	50
Olefins (vol. %, max)	25
E200 (vol. %)	70-30
E300 (vol. %)	100-70
Maximum Vapor Pressure Oct. 1 - March 31 (psi) April (psi) May (psi) June 1 - Sept. 30 (psi)	9.0 10.0 9.0 7.0
Oxygen and Oxygenates Minimum Content Nov. 1 - March 31 (vol. %, ethanol) (mass %, oxygen; other than ethanol) April 1 - Oct. 31 (mass %) Maximum Content	10 2.7 0 The maximum oxygen content shall not exceed 4.0% by weight for ethanol and 3.5% by weight for other oxygenates, and shall comply with the requirements of A.R.S. § 41-2123.
Federal Complex Model VOC Emissions Reduction Percentage May 1 through Sept. 15 (%) (Federal Complex Model settings: summer, Area Class B, Phase 2)	≥ 25.0

NOTE: Arizona Final Rule: Arizona Administrative Code, Title 20. Commerce, Banking, and Insurance, Chapter 2. Department of Weights and Measures, Article 7, Motor Fuels and Petroleum Products, Supp. 99-3, November 5, 1999.

Table X3.2
ARIZONA CBG^A
Wintertime Requirements
(November 2-March 31)

Regulated Property	Limits
Sulfur (ppm by weight, max)	80
Aromatics (vol. %, max)	30
Olefins (vol. %, max)	10
90% Distillation Temperature (T90) (°F)	330
50% Distillation Temperature (T50) (°F)	220
Vapor Pressure (psi, max)	9.0
Oxygenate - Ethanol Minimum oxygenate content (vol. %, ethanol) Maximum oxygen content (mass %, oxygen; shall comply with the requirements of A.R.S. § 41-2123.) Alternative oxygenates may be used if approved by the Director according to A.R.S. §41-2124(D).	10% ethanol by volume 4.0

NOTE: Arizona Final Rule: Arizona Administrative Code, Title 20. Commerce, Banking, and Insurance, Chapter 2. Department of Weights and Measures, Article 7, Motor Fuels and Petroleum Products, Supp. 99-3, November 5, 1999.

^A These requirements were effective November 1, 2000.

Table X3.3

**ARIZONA CBG
"Table 1-Type 1 Gasoline Standards"**

	Non-averaging Option	Averaging Option		
	A	B	C	D
Performance Standard/Fuel Property ^B	Per-Gallon (minimum)	Average	Minimum (per-gallon)	Maximum (per-gallon)
VOC Emission Reduction (%) May 1 - Sept. 15	≥ 27.5	≥ 29.0	≥ 25.0	N/A
NOx Emission Reduction (%) May 1 - Sept. 15	≥ 5.5	≥ 6.8	N/A	N/A
NOx Emission Reduction (%) Sept. 16 – Nov. 1 and April 1 - April 30 ^C	≥ 0.0	N/A	N/A	N/A
Oxygen content: ethanol, (% by weight unless otherwise noted) Nov. 2 - March 31 ^C April 1 - Nov. 1	N/A 0.0 ^A	N/A N/A	N/A 0.0	N/A 4.0
Oxygen content: other than ethanol, (% by weight) Nov. 2 - March 31 ^C April 1 - Nov. 1	N/A 0.0	N/A N/A	N/A 0.0	N/A 2.7

NOTE: Arizona Administrative Code, Title 20. Commerce, Banking, and Insurance, Chapter 2. Department of Weights and Measures, Article 7, Motor Fuels and Petroleum Products, Supp. 99-3, November 5, 1999. Notice of Final Rulemaking, Title 20. Commerce, Banking, and Insurance, Chapter 2. Department of Weights and Measures, Article 7, Motor Fuels and Petroleum Products, February 9, 2001.

^A Maximum oxygen content must comply with the EPA oxygenate waiver requirements.

^B Dates represent compliance dates for service stations and fleet owners.

^C Registered suppliers shall certify all Arizona CBG as Type 2 gasoline meeting the standards in Table 2 beginning November 2 through March 31.

Table X3.4

**ARIZONA CBG
"Table 2 - Type 2 Gasoline Standards"**

	Averaging Option		Non-averaging Option	
	A	B	C	
Fuel Property	Maximum Standard (per gallon)	Averaging Standard ^A	Flat Standard ^A (per gallon maximum)	Units of Standard
Sulfur Content	80	30	40	Parts per million by weight
Olefin Content	10.0	4.0	6.0	% by volume
90% Distillation Temperature (T90)	330	290	300	Degrees Fahrenheit
50% Distillation Temperature (T50)	220	200	210	Degrees Fahrenheit
Aromatic Hydrocarbon Content	30.0	22.0	25.0	% by volume
Oxygen content: ethanol ^D				
Nov. 2 - March 31	10% ethanol	--	10% ethanol	% by vol.
April 1 - Nov. 1	2.7	--	2.7 ^B	% by weight
Oxygen content: other than ethanol ^D				
Nov. 2 - March 31	3.5 ^C	--	3.5 ^C	% by weight
April 1 - Nov. 1	2.7	--	2.7 ^B	% by weight

NOTE: Dates represent compliance dates for service stations and fleet owners. Arizona Administrative Code, Title 20. Commerce, Banking, and Insurance, Chapter 2. Department of Weights and Measures, Article 7, Motor Fuels and Petroleum Products, Supp. 99-3, November 5, 1999. Notice of Final Rulemaking, Title 20. Commerce, Banking, and Insurance, Chapter 2. Department of Weights and Measures, Article 7, Motor Fuels and Petroleum Products, February 9, 2001.

^A Instead of the standards in columns B and C, a registered supplier may elect to comply with the standards contained in column A, and R20-2-751 (F), (G), and (H) for the use of the PM.

^B Maximum oxygen content shall comply with the EPA oxygenate waiver requirements.

^C Non-ethanol oxygenate is allowed only if approved by the Director under A.R.S. § 41-2124(D). Maximum oxygen content shall comply with the EPA oxygenate waiver requirements.

^D A registered supplier shall certify all Arizona CBG using ethanol as the oxygenate beginning November 2 through March 31. Alternative oxygenates may be used if approved by the Director under A.R.S. § 41-2124(D).

X3.2 Clark County, Nevada

X3.2.1 On April 22, 1999, the District Board of Health of Clark County approved a final rule establishing Cleaner Burning Gasoline specifications for Clark County. The rule adds a new section to Clark County's Air Pollution Control Regulations "Section 54 - Cleaner Burning Gasoline (CBG): Wintertime Program".

X3.2.2 Under the cleaner burning gasoline rule, all fuel sold in Clark County, Nevada, during the control period of November 1 to March 31, is required to meet a maximum sulfur standard of 80 parts per million by weight and a maximum aromatic hydrocarbon standard of 30.0 percent by volume. Compliance with the standard can be met by either a flat limit or through averaging.

X3.2.3 Under the rule, "No person shall sell, offer for sale, supply, offer for supply, or transport California gasoline CBG which has a sulfur content exceeding 80 parts per million by weight" and "no person shall sell, offer for sale, supply, offer for supply, or transport California gasoline CBG which has a aromatic hydrocarbon content exceeding 30.0 percent by volume."

X3.2.4 Table X3.5 summarizes gasoline specifications for Clark County. There are two alternative ways to be in compliance.

Table X3.5

**CLARK COUNTY
Specifications for Cleaner Burning Gasoline^A**

	Compliance Method	Compliance Method	
	I	II	
	Flat Limit	Average	Cap
Sulfur, ppm	40	30	80
Aromatic Hydrocarbons %	25	22	30

^A Final Rule, District Board of Health of Clark County, Air Pollution Control Regulations, Section 54- Cleaner Burning Gasoline (CBG): Wintertime Program, April 22, 1999.

X3.2.5 To meet the flat limit in Method I, each gallon transported to Clark County must comply. Under Method II, a marketer can demonstrate, through record keeping, the average level is being met while no retail gallon sampled can exceed the Cap.

X3.3 Atlanta, Georgia

X3.3.1 The Georgia Department of Natural Resources requires that all gasoline sold in the Atlanta ozone nonattainment area must meet the following Reid vapor pressure and sulfur limits.^A Beginning June 1, 1999, during the period from June 1 to September 15 of any calendar year, no "person may produce, store, transport, supply, offer to supply, transfer or otherwise handle, sell, offer for sale, or dispense gasoline" that does not meet a 7.0 psi RVP.

X3.3.2 An ethanol blend is considered in compliance if the Reid vapor pressure does not exceed 8.0 psi, provided that the gasoline contains denatured, anhydrous ethanol and the concentration of ethanol, excluding the required denaturing agent, is at least 9 percent and no more than 10 percent (by volume). Georgia established sulfur content requirements beginning in April 1999. Georgia requires that the sulfur content of all gasoline supplied by each producer or importer to the Atlanta area shall not exceed an annual average of 30 ppm (by weight) and a per-gallon cap of 150 ppm (by weight). During the period June 1 through September 15, sulfur content shall not exceed a per-gallon cap of 80 ppm (by weight). [See X2, "Covered Areas" for status of counties subject to RFG].

X3.4 Birmingham, Alabama

On April 13, 1999, the Alabama Environmental Management Commission adopted a rule establishing low-RVP and sulfur content requirements for fuels sold in Jefferson and Shelby Counties. The rule became effective May 20, 1999. On October 24, 2000, the Alabama Environmental Management Commission adopted revisions to *Chapter 335-3-20: Control of Fuels* to extend the low-sulfur requirements for the Birmingham nonattainment area through the summer of 2003. This Rule became effective December 1, 2000. The low-sulfur requirements have expired and are no longer in effect.

During the period from June 1 to September 15, the Reid vapor pressure of gasoline sold in Jefferson and Shelby Counties shall not exceed 7.0 psi. An ethanol blend is considered in compliance if its measured Reid vapor pressure does not exceed 8.0 psi, provided that the gasoline contains denatured, anhydrous ethanol, and the concentration of ethanol, excluding the required denaturing agent, is at least 9 percent and no more than 10 percent (by volume) of the gasoline.

Through September 15, 2003, the sulfur content of all gasoline supplied (during the control period of June 1 to September 15) by each producer or importer to comply with the Reid vapor pressure limits required in Jefferson and Shelby Counties was required to not exceed an average of 150 ppm by weight) and a per-gallon cap of 500 ppm (by weight). For each calendar year, the sulfur content was required to be averaged on a volume-weighted basis over the pool of gasoline supplied by the producer or importer to comply with the applicable Reid vapor pressure requirements.

^A The requirements apply to the following 45-counties: Banks, Barrow, Bartow, Butts, Carroll, Chattooga, Cherokee, Clarke, Clayton, Cobb, Coweta, Dawson, DeKalb, Douglas, Fayette, Floyd, Forsyth, Fulton, Gordon, Gwinnett, Hall, Haralson, Heard, Henry, Jackson, Jasper, Jones, Lamar, Lumpkin, Madison, Meriwether, Monroe, Morgan, Newton, Oconee, Paulding, Pickens, Pike, Polk, Putnam, Rockdale, Spalding, Troup, Upson and Walton.

X4. EPA PHASE I COMPLEX MODEL STANDARDS [EXPIRED]

X4.1 Federal Phase I RFG requirements were implemented in January 1995, and were in effect until December 31, 1999. Phase I gasoline was required to meet the specifications and emission reduction requirements established by the U.S. EPA, effective January 1, 1995. During the period January 1, 1998 through December 31, 1999, refiners and importers were subject to Phase I complex model standards. Beginning January 1, 2000, refiners were required to meet Phase II complex model standards.

X4.2 Under Phase I Complex Model Standards (expired 12/31/99 and no longer used), refiners were required to meet both performance standards (VOCs, NOx, toxics) and content standards (oxygen, benzene). The standards were more stringent if the refiner elected to meet them on an averaging, rather than per-gallon basis. Phase I Complex Model Standards are identified in Table X4.1.

TABLE X4.1

EPA PHASE I COMPLEX MODEL STANDARDS FOR FEDERAL RFG

Emissions Reductions & Properties	Phase I (1995-1999)		
	Per gallon	Average	
		Average limit	Per Gallon
VOC Reduction, %^A			
EPA Control Region 1, minimum	35.1	36.6	32.6
EPA Control Region 2, minimum	15.6	17.1	13.1
NOx Reduction, %			
VOC control period, minimum	0	1.5	N/A
Non-VOC control period, minimum			
Toxics Reduction, %, minimum	15.0	16.5	N/A
Oxygen, mass %, min.	2.0	2.1	1.5 ^B
Benzene, volume %, maximum	1.00	0.95	1.30

^A VOC reductions apply to VOC control period only. In addition, under the Complex Model, RFG Covered Areas are subject, during VOC control periods, to reduction requirements as well as Federal Phase II volatility standards.

^B EPA increased this standard for certain RFG covered areas failing to meet compliance surveys. See EPA Notices, "Change in Minimum Oxygen Content Requirement for Reformulated Gasoline", Federal Register, Vol. 62, No. 147, July 31, 1997 p. 41047-410949, and Federal Register, Vol. 63, No. 131, p. 37112-37114, July 9, 1998.

X5. CALIFORNIA PHASE 2 RFG STANDARDS [EXPIRED]

X5.1 All spark-ignition engine fuel produced between March 1, 1996 and December 30, 2003 for sale in California was required to comply with California Phase 2 Reformulated Gasoline (CaRFG2) regulations. Cap limits applied starting April 15, 1996 to sales and supplies of gasoline throughout the gasoline distribution system except for gasoline being supplied from a bulk storage facility or being dispensed into a motor vehicle. After June 1, 1996 the cap standards applied to all gasoline being sold or supplied in California. Table X5.1 lists standards for CaRFG2.

X5.2 General requirements for CaRFG, including deposit control additives and the elimination of lead, were implemented in 1992. Prohibition of manganese and the limitation of the phosphorus content in California unleaded gasoline occurred in 1977. The regulations appear in the California Code of Regulations, Title 13, sections 2250 - 2272.

X5.3 The California Air Resources Board adopted amendments to the Gasoline Deposit Control Additive Regulation (Section 2257, Title 13, CCR). The amendments were effective on July 16, 1999. Under the revised regulation, CARB required that a gasoline formulation (i) must meet an intake valve performance standard of 50 milligrams per valve averaged across all four intake valves, (ii) does not result in a flow loss of more than five percent for any fuel injector, and (iii) requires a new performance standard that combustion chamber deposits not exceed 1300 milligrams total deposit weight, when averaged over all four combustion chambers, or, does not result in more than 140 percent total deposit weight from all four combustion chambers, relative to the gasoline formulation containing no additive.

X5.4 The CaRFG2 specifications address eight different fuel properties. The CaRFG2 regulations, which overall were more restrictive than those adopted by the U. S. EPA for federal reformulated gasoline; allowed producers the option of meeting flat limits or averaging limits. Averaging was permitted for all properties other than oxygen content and vapor pressure. The averaging limits were numerically more stringent than comparable flat limits. CaRFG2 regulations also contained caps, which are absolute and were not to be exceeded by any gallon of California reformulated gasoline.

X5.5 CARB established a primary statewide oxygen range for CaRFG2 of 1.8 - 2.2 mass% for gasoline. Alternately, producers could have use the California Predictive Model (see X6.7) to sell gasoline with an oxygen content between 0 and 3.5 mass%. During the winter months, gasoline sold or supplied in the South Coast Area (which includes the counties of Los Angeles, Orange, Riverside, San Bernadino, and Ventura) and Imperial County was required to meet a minimum of 1.8 mass%. Prior to April 24, 2006, Federal RFG regulations prohibited the sale of formulations below the minimum 2.0 mass% (1.5% averaging minimum, per Table 1) in federal RFG covered areas.

X5.6 CARB CaRFG2 regulations limited vapor pressure statewide to 48.3 kPa (7.00 psi), during the summer control season, which was longer than the EPA control season. Table X5.2 lists the air basins, the regulatory control periods, and the regulatory control periods for gasoline producers and importers.

Table X5.1

**CARB PHASE 2 REFORMULATED GASOLINE REGULATIONS [Expired]
CaRFG2 Average and Flat Limits with Per Gallon Maximums and Minimums**

Regulated Property	CARB Phase 2 (1996 - 2003) ^A		
	Flat Limits	Averaging Limits	Max Per Gallon Cap
Aromatics, max, vol. %	25.0	22.0	30.0
Benzene, max, vol. %	1.00	0.80	1.20
Olefins, max, vol. %	6.0	4.0	10.0
Oxygen, mass %	1.8 ^B min 2.2 max	Not Applicable	3.5 ^C
Vapor Pressure, max, kPa (psi) (RVP Control Period)	48.3 (7.00)	Not Applicable	48.3 (7.00)
Sulfur, max, ppm (m/m)	40	30	80
Distillation Temperature, max, °C (°F), at % evaporated			
50 vol. %	98.9 (210)	93.3 (200)	104.4 (220)
90 vol. %	148.9 (300)	143.3 (290)	165.6 (330) ^D

CARB Phase 2 Reformulated Gasoline Regulations, Title 13, California Code of Regulations, Sections 2260-2272.

^A Alternative formulations with different limits could be certified by CARB, based on motor vehicle emissions testing, or on the CARB Predictive Model.

^B Flat limits applied unless predictive model was used. In CARB winter oxygenate areas, a 1.8% minimum oxygen content was required during the control season. In California Federal reformulated gasoline areas, a minimum 2.0% oxygen content was required.

^C A higher oxygen cap limit was adopted by CARB on December 11, 1998, and became effective March 31, 1999. Where the predictive model was used, gasoline could contain up to 3.5% oxygen, or no oxygen. Where the predictive model was used in Federal RFG areas, a minimum of 1.5% oxygen was required.

^D Applied to all California gasolines, including alternative formulations certified by CARB. A 154°C (310°F) limit may have been required for some fuels.

Table X5.2

**CARB PHASE 2 REFORMULATED GASOLINE REGULATIONS
RVP Control Periods in California [Expired]**

Air Basin	Regulatory Control Period	Regulatory Control Period (Producers & Importers)
South Coast and Ventura County	April 1 - October 31	March 1 - October 31
San Diego	April 1 - October 31	March 1 - October 31
Mojave Desert	April 1 - October 31	March 1 - October 31
Salton Sea	April 1 - October 31	March 1 - October 31
Great Basin Valley	May 1 - September 30	April 1 - September 30
San Francisco Bay Area	May 1 - October 31	April 1 - October 31
San Joaquin Valley	May 1 - October 31	April 1 - October 31
Sacramento Valley	May 1 - October 31	April 1 - October 31
Mountain Counties	May 1 - October 31	April 1 - October 31
Lake Tahoe	May 1 - October 31	April 1 - October 31
North Coast	June 1 - September 30	May 1 - September 30
Lake County	June 1 - September 30	May 1 - September 30
Northeast Plateau	June 1 - September 30	May 1 - September 30
North Central Coast	June 1 - October 31	May 1 - September 30
South Central Coast ex. Ventura Co	June 1 - October 31	May 1 - October 31

^A RVP control periods were amended by CARB on August 27, 1998 and became effective September 21, 1998.

X5.7 Producers in California were permitted to use the California Predictive Model to establish specifications for an alternative gasoline formulation in lieu of meeting the CaRFG2 specifications. Through the use of the Predictive Model, producers would show that an alternative formulation would result in emissions reductions equivalent to or better than a fuel meeting the CaRFG2 specifications.

X5.8 The CaRFG2 Predictive Model is a set of three equations which determine the change in exhaust hydrocarbon emissions, exhaust emissions of oxides of nitrogen, and the combined emissions of four toxic air contaminants (1,3-butadiene, benzene, formaldehyde and acetaldehyde). The CaRFG2

Predictive did not address non-exhaust emissions. Table X6.3 describes the model terms included in the exhaust predictive model for CaRFG2.

X5.9 CaRFG2 regulations also allowed for an alternative CaRFG2 formulation if it could be shown through the vehicle testing option ("California Test Procedure for Alternative Specifications for Gasoline", section 2266, Title 13 California Code of Regulations) that emissions resulting from the use of the alternative formulation would result in emissions reductions equivalent to or better than a fuel meeting the CaRFG2 specifications.

Table X5.3

**CARB PHASE 2 PREDICTIVE MODEL
Exhaust Terms Included in the CaRFG2 Model [Expired]**

Model Terms	Exhaust		
	Total Hydrocarbons	NOx	Toxics ^A
Vapor Pressure	X	X	X
Vapor Pressure x T50	X		
Vapor Pressure x Oxygen		X	
Oxygen	X	X	X
(Oxygen) ^z		X	
Oxygen x T90	X		
Aromatics	X	X	X
(Aromatics) ^z	X		
Aromatics x T90	X	X	
Aromatics x Oxygen		X	
Aromatics x Sulfur	X		
Benzene			X
Olefins	X	X	X
Sulfur	X	X	X
T50	X	X	X
(T50) ^z	X		
T50 x T90		X	
T90	X	X	X
(T90) ^z	X		

^A Toxics are potency weighted.