United States
Environmental Protection
Agency

Air and Radiation

EPA420-R-99-025
April 1999

Phase II RFG

Report on Performance Testing

Printed on Recycled Paper

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Fuels and Energy Division
Office of Air Transportation and Air Quality
U.S. Environmental Protection Agency

NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position, or regulatory action.

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Acknowledgment

This report was peer reviewed by the Phase II RFG Implementation Workgroup's technical steering committee. Members of the technical steering committee are listed in Appendix C.

This report was also reviewed by John Hornback, director of the Kentucky Department for Environmental Protection's Division for Air Quality and co-chair of the workgroup, and by Marlin Gottschalk, manager of the Georgia Department of Natural Resources's Mobile Sources and Area Sources Program.

I. Executive Summary

The federal reformulated gasoline (RFG) program was introduced in January 1995. RFG is a specially blended gasoline that burns cleaner, reducing vehicle emissions of air pollutants that cause smog. Congress requires the RFG program in those cities with the worst smog problems. Other areas may choose to participate in the program. Seventeen states and the District of Columbia currently use RFG. About 30 percent of the U.S. gasoline supply is reformulated.

The second phase of the RFG program will begin in January 2000. Phase II RFG will achieve even greater vehicle emission reductions than Phase I, although the gasoline blend will be similar in many ways. To ensure that any vehicle performance problems with Phase II RFG would be identified before the fuel is introduced to the public, the U.S. Environmental Protection Agency (EPA) conducted a fleet testing program in 1998.

EPA tested 374 in use vehicles in three cities over a period of three to five months. Conditions during testing included subfreezing temperatures in the north and record heat in the south. The combined test fleets drove over one million miles with Phase II RFG. No performance problems with Phase II RFG were reported.

Fleets that participated in the testing program include the Boston Police Department, Elk Grove Village in suburban Chicago, and the Houston Lighting & Power Company. Vehicles in these fleets were generally well maintained.

Well maintained vehicles should experience no unusual performance problems with Phase II RFG. Of course, as vehicles age, parts wear out, so maintenance is the key to good performance with any fuel.

In a separate study by Southwest Research Institute, fuel economy with Phase II RFG was compared to Phase I RFG with 12 vehicles of various makes, ages, and mileage under normal driving conditions. The results indicate no statistically significant difference between the fuels. The results are consistent with other fuel economy studies which show that fuels of equivalent energy content will produce equivalent fuel economy.

Testing was also conducted with small engines, including 177 pieces of utility, lawn, and garden equipment, and with marine and motorcycle engines. No performance problems were reported.

In summary, no difference in vehicle performance or fuel economy is expected when Phase II RFG replaces Phase I RFG. In addition, no difference in performance is expected with small engines, marine engines, or motorcycles.

II. Background

A. RFG Program

Section 211(k) of the Clean Air Act (CAA) directs EPA to issue regulations establishing a reformulated gasoline program that will significantly reduce vehicle emissions that contribute to smog. On February 16, 1994, EPA published a final rule establishing various content and emission reduction standards for RFG, including provisions for enforcement of RFG standards (59 FR 7716). The purpose of the RFG program is to improve air quality by requiring that gasoline sold in certain areas of the U.S. be reformulated to reduce emissions of toxics and smog-forming compounds from motor vehicles.

Section 211(k) mandates that RFG be sold in the nine specific metropolitan areas with the most severe summertime ozone levels as measured during the period 1987 through 1989; RFG must also be sold in any ozone nonattainment area subsequently reclassified as a severe area. Other ozone nonattainment areas may choose to participate or "opt in" to the program. Ground level or tropospheric ozone is the primary ingredient of smog. Ground level ozone results from a reaction between such gases as volatile organic compounds (VOCs) and oxides of nitrogen (NOx) that are emitted from vehicles and other sources.

The Act mandates certain requirements for the RFG program. Section 211(k)(1) directs EPA to issue regulations that:

> require the greatest reduction in emissions of ozone forming volatile organic compounds (during the high ozone season) and emissions of toxic air pollutants (during the entire year) achievable through the reformulation of conventional gasoline, taking into consideration the cost of achieving such emission reductions, any nonair-quality and other air-quality related health and environmental impacts and energy requirements.

Section 211(k) specifies the minimum requirement for reduction of VOCs and toxics for 1995 through 1999, or Phase I of the RFG program; the section specifies that EPA must require the more stringent of a specified fuel formula or an emission reduction performance standard, measured on a mass basis, equal to 15 percent of baseline emissions. Baseline emissions are the emissions of 1990 model year technology vehicles operated on a specified baseline gasoline. Section 211(k) compositional specifications for RFG include a 2.0 weight percent oxygen minimum standard and a 1.0 volume percent benzene maximum standard. Section 211(k) also specifies that emissions of NOx may not increase in RFG over baseline emissions.

For the year 2000 and beyond, or Phase II of the RFG program, the Act specifies that the VOC and toxic performance standards must be no less than either a specified fuel formula or a 25 percent reduction from baseline emissions, whichever is more stringent. EPA can adjust these standards upward or downward taking into account such factors as technological feasibility and cost, but in no case can the standards be less than 20 percent.

Shortly after passage of the CAA Amendments in 1990, EPA entered into a regulatory negotiation with interested parties to develop specific proposals for implementing the RFG program. In August 1991, the negotiating committee reached consensus on a program outline that would form the basis for a notice of proposed rulemaking, addressing emission content standards for Phase I (1995-1999), emission models, certification, enforcement, and other important program elements.

The regulatory negotiation conducted by EPA did not address the Phase II VOC and toxic standards for RFG, nor did it address a reduction in NOx emissions beyond the statutory cap imposed under section 211(k)(2)(A). The final rule promulgated by EPA closely followed the consensus outline agreed to by various parties in the negotiated rulemaking process. The final rule also adopted a NOx emission reduction performance standard for Phase II RFG, relying on authority under section 211(c)(1)(A).

Reformulated Gasoline Average Emission Reduction Requirements*

	Phase I**	Phase II**
Volatile Organic Compounds	17%	27%
Nitrogen Oxides	2%	7%
Toxics	17%	22%

*Reductions are from 1990 nationwide baseline.
**Complex model averaged standards for VOC-control Region 2 (i.e., northern areas).

The Phase I RFG program is designed to reduce the air pollution that causes smog by 36,000 tons per year in the areas that use RFG, compared to conventional gasoline -- the equivalent of eliminating the emissions from over eight million vehicles. When Phase II RFG replaces Phase I, the program is designed to reduce smog pollutants by an additional 45,000 tons per year in RFG areas, for a combined equivalent of eliminating the emissions from over 16 million vehicles.

Analysis of fuel data submitted to EPA by industry for compliance purposes indicates that in each year since the RFG program's introduction in 1995, VOC and toxic reductions from the RFG program have exceeded program requirements. Preliminary data analysis for 1998 indicates that, on average, all Phase I emission reduction standards are being met and exceeded. In 1998, most RFG already exceeded the Phase II RFG average performance standard for toxics, and some RFG in the Northeast exceeded Phase II RFG emission reduction standards for NOx in the ozone control season (i.e., the summer months). At this time, refiners are still making incremental investments to produce adequate volumes of compliant Phase II RFG.

Air quality monitoring data for 1995, the first year of the RFG program, shows a 43 percent reduction in benzene in the ambient air in RFG areas, according to EPA's *National Air Quality and Emission Trends Report, 1995*. A greater percentage of monitoring sites in RFG areas showed statistically significant decreases in average benzene than did sites in non-RFG areas. The RFG program limits benzene. Still, to overcome the difficulties inherent in linking changes in the ambient air to particular pollution reduction programs like RFG, an independent analysis of the data was conducted by Sonoma Technology, Inc. The analysis of the 1995 ambient air monitoring data indicates that there is a strong case that the ambient reductions in benzene resulted from RFG.

B. Implementation Workgroup

In April 1997, EPA formed a stakeholder workgroup under the Federal Advisory Committee Act to focus on Phase II RFG implementation issues. The Phase II RFG Implementation Workgroup was established by the Clean Air Act Advisory Committee's Mobile Source Technical Review Subcommittee. The workgroup includes representatives of the automobile and oil industries, environmental and public health groups, and state agencies and associations. The goal of the workgroup is to provide factual information to the public by working together to identify, gather, and analyze data on Phase II RFG. Members of the workgroup are listed in Appendix A. The workgroup formed teams to focus on testing and education activities.

III. Vehicle Performance Test Program

To ensure that any vehicle performance problems with Phase II RFG would be identified before the fuel is introduced to the public, the testing team recommended a fleet testing program with Phase II RFG, compared to Phase I RFG. The fleet testing recommendation was adopted by the workgroup, and the Mobile Source Technical Review Subcommittee. Members of the testing team are listed in Appendix B.

The testing team also recommended formation of a technical steering committee to guide development of the fleet testing program. Members of the technical steering committee are listed in Appendix C.

A. Design

The purpose of the test program was to identify any performance problems that might be associated with Phase II RFG before the fuel is introduced to the public in January 2000 by conducting performance testing in several cities representative of RFG areas. Boston, Chicago, and Houston were selected by the workgroup as test program sites.

The technical steering committee worked with EPA to develop a test plan, “Evaluation of On-Highway Motor Vehicles Operated on Federal Phase II Reformulated Gasoline,” included as Appendix D. The plan is similar to the test program conducted by the California Air Resources Board for the introduction of its cleaner burning gasoline program in June 1996, but smaller in scale.

From February to August 1995, the California Air Resources Board conducted a performance and compatibility test program with its cleaner burning gasoline (CaRFG). With a fleet of 1466 vehicles, 829 test vehicles were driven over five million miles with CaRFG. The workgroup believes that the California data is applicable to Phase II RFG since the testing was conducted on a wide mix of vehicle types and ages with a fuel more severely reformulated and designed to burn cleaner than is expected for Phase II RFG. A comparison of the properties of Phase II RFG and CaRFG is included in Appendix E.

California’s test results indicate that CaRFG performed as well as conventional fuel in terms of driveability, starting, idling, acceleration, power, and safety. There was no significant difference between the frequency of problems in the test and control fleets. Newer vehicles did not experience problems. Historical maintenance and repair data indicate an increasing rate of failures in fuel system components associated with aging irrespective of the fuel used.

The workgroup determined that the California testing results are relevant for Phase II RFG. However, several data gaps were identified, particularly vehicle performance with ethanol-oxygenated fuels and vehicle performance in cold temperatures and the shoulder season (i.e., the period of time in late spring and early autumn when unseasonably cold temperatures may occur). Therefore, EPA’s test program was designed to fill gaps in existing data.

Funding for the test fuel for Boston and Chicago was provided by the American Petroleum Institute, Oxygenated Fuels Association, and American Methanol Institute. Management of fuel distribution for the Boston and Chicago fleets was handled by the Lake Michigan Air Directors Consortium. EPA provided test fuel for Houston. EPA entered into a contract with each participating fleet that covered identification of the test fleet, vehicle inspection, incident reporting, and fuel provisions. An example of a statement of work for these contracts is included in Appendix F.

To carry out the test plan, EPA technicians from the National Vehicle and Fuel

Emissions Laboratory inspected the fuel systems of each test and control vehicle included in the test program. Fuel system inspections were conducted three times over five months in Boston and Chicago, and twice over three months in Houston. For each test and control vehicle inspected, relevant information such as mileage and vehicle description was noted on fuel system inspection forms. Examples of these forms are included with the test plan in Appendix D.

The test plan also includes driveability incident logs that were designed to capture information on vehicle performance measures such as starting, running, and idling. EPA provided copies of the driveability incident log to participating fleets. The driveability incident log is included in Appendix D.

B. Fuel

The technical steering committee developed four formulations of test fuel for the fleet testing program that meet the standards for Phase II RFG: winter fuel oxygenated with MTBE, winter fuel oxygenated with ethanol, summer fuel oxygenated with MTBE, and summer fuel oxygenated with a mixture of MTBE and TAME. The test fuel formulations are equivalent to the average or 50th percentile fuel expected for Phase II RFG. The test fuel property specifications developed by the technical steering committee are shown in the test plan in Appendix D. The technical steering committee also developed allowable ranges of parameters and maximum blending fractions for each test fuel to assure that the test fuels would be representative of actual refinery blends. The fractions and ranges are included in the test plan in Appendix D. The properties of the test fuels used in the fleet testing program are shown in Table 1.

Table 1 - Test Fuel Properties

	Summer MTBE	Summer MTBE + TAME	Winter MTBE	Winter Ethanol
Oxygenate, vol%	11.2	10.81 MTBE 3.288 TAME	11.7	9.74
RVP, psi	6.8	6.75	12.8	13.1
Sulfur, ppm	155	169	298	309
Aromatics, vol%	24.5	23.5	23.85	25.2
Olefins, vol%	12	13	10.5	11
Benzene, vol%	1.0	1.0	0.98	0.999
T10, F	139.7	138.5	106.5	110.4
T50, F	205.7	192.7	190.3	182.7
T90, F	312.5	308.2	331.3	335.3

Test fuel was manufactured by Phillips Chemical Company. Certificates of analysis for the four fuel formulations used in the testing program are included in Appendix G. Fuel property analyses were also performed for verification by EPA's National Vehicle and Fuel Emissions Laboratory (NVFEL) in Ann Arbor. NVFEL analyses confirmed that the fuels fell within acceptable ranges for Phase II RFG, or within test method precision range, which specifies an acceptable range of variability. NVFEL analyses are included in Appendix H.

During the testing program, Boston received five test fuel deliveries totaling 39,914 gallons. Of the total, 23,947 gallons were the winter fuel oxygenated with MTBE, 8,073 gallons were the summer fuel oxygenated with MTBE, and 7,894 gallons were the summer fuel oxygenated with MTBE and TAME.

Elk Grove Village in suburban Chicago received three fuel deliveries totaling 24,432 gallons. Of the total, 16,272 gallons were the winter fuel oxygenated with ethanol, and 8,160 gallons were the summer fuel oxygenated with MTBE.

Houston received three test fuel deliveries totaling 23,448 gallons. All test fuel used in Houston was the summer fuel oxygenated with MTBE.

C. Fleets

Three vehicle fleets in three cities participated in the program. Boston, Chicago, and Houston were selected by the testing team and approved by the workgroup as representative of geographic areas participating in the RFG program. The National Association of Fleet Administrators provided assistance in locating participating fleets.

Testing in Boston and suburban Chicago's Elk Grove Village was conducted from March through July. In Houston, the test period was June through August. Daily minimum and maximum temperatures for the test period for Boston, Chicago, and Houston are listed in Appendix I.

In Boston, the Police Department agreed to participate in the fleet testing program. The fleet was composed of two police precincts; one precinct provided a test fleet and another precinct provided a control fleet. Due to the preexisting sizes of the fleet at each precinct, it was not possible to find a closer match between the number of vehicles in the test and control fleets.

Table 2 - Boston Police Department Test Fleet

					Test Fuel		Control Fuel	
Year	Total	Cars	Trucks		Cars	Trucks	Cars	Trucks
99	1	0	1		0	0	0	1
98	4	3	1		0	1	3	0
97	35	35	0		23	0	12	0
96	9	9	0		8	0	1	0
95	20	17	3		8	2	9	1
94	2	2	0		0	0	2	0
93	10	8	2		5	1	3	1
92	1	1	0		1	0	0	0
91	9	9	0		6	0	3	0
90	2	0	2		0	1	0	1
89	2	2	0		1	0	1	0
88	2	1	1		1	1	0	0
	97	87	10		53	6	34	4

In suburban Chicago, Elk Grove Village agreed to participate in the program. The fleet is composed of vehicles used in the full range of municipal activities, including fire and police protection, and parks and sewer maintenance.

Two motorcycles belonging to Elk Grove Village also used Phase II RFG during the test program. The motorcycles are not included in the table or in the results because of their small number and because there were no control motorcycles. No performance problems were reported with the two motorcycles using Phase II RFG. For further information on motorcycle performance with Phase II RFG, see section VI for a description of the motorcycle testing program conducted by Harley-Davidson.

Table 3 - Elk Grove Village Test Fleet

					Test Fuel		Control Fuel	
Year	Total	Cars	Trucks		Cars	Trucks	Cars	Trucks
97	4	0	4		0	2	0	2
96	14	13	1		6	1	7	0
95	11	10	1		5	0	5	1
94	13	11	2		6	1	5	1
93	14	13	1		6	0	7	1
92	14	13	1		7	0	6	1
91	8	7	1		3	1	4	0
90	3	3	0		2	0	1	0
89	1	1	0		0	0	1	0
88	8	3	5		2	3	1	2
87	1	1	0		0	0	1	0
86	2	0	2		0	1	0	1
83	1	0	1		0	1	0	0
82	1	0	1		0	0	0	1
81	1	0	1		0	1	0	0
79	1	0	1		0	0	0	1
73	1	0	1		0	1	0	0
	98	75	23		37	12	38	11

In Houston, the Lighting & Power Company agreed to participate in the test program. Unlike the Boston and Chicago fleets, most of the vehicles in the Houston fleet are trucks.

Table 4 - Houston Lighting & Power Test Fleet

					Test Fuel		Control Fuel	
Year	Total	Cars	Trucks		Cars	Trucks	Cars	Trucks
97	53	15	38		11	21	4	17
96	12	5	7		3	6	2	1
95	59	1	58		1	30	0	28
94	15	0	15		0	4	0	11
93	10	1	9		0	4	1	5
92	0	0	0		0	0	0	0
91	30	23	7		12	2	11	5
	179	45	134		27	67	18	67

The fleets involved in the testing program were composed primarily of General Motors and Ford cars and trucks, with model years ranging from 1973 to 1999. Trucks include sport utility vehicles, vans, pickups, and step vans. The practicalities of finding fleets of an appropriate size, in the geographic locations desired, at the time needed, necessarily limited potential options in terms of representing all automobile manufacturers. The vehicle technologies tested are generally representative of vehicle technologies employed over the same time period.

D. Vehicle Performance

For the purposes of this fleet testing program, the term “incident” means that a fuel system component was adjusted, repaired, or replaced other than through regular scheduled maintenance. There were six incidents during the course of the testing program involving vehicles using Phase II RFG test fuel.

Boston

During the test program, one fuel pump from a 1988 truck in the Boston Police fleet using Phase II RFG was sent to the vehicle manufacturer for analysis. The pump symptom was a leak at the pump outlet port. The manufacturer determined that the pump’s performance was still within specifications. The manufacturer’s examination indicated that the cause of the leak was mechanical and not fuel related. It was most likely to have resulted from damage to the fitting that screws into the pump outlet port. The manufacturer’s analysis is included in Appendix J. The incident occurred during the use of summer test fuel oxygenated with MTBE and TAME.

Elk Grove Village

Four incidents were reported on vehicles using Phase II RFG test fuel during the course of testing in suburban Chicago’s Elk Grove Village. All four incidents occurred with the winter test fuel oxygenated with ethanol.

In three cases, electric fuel pumps failed on police vehicles that ranged in age from 1992 to 1996 with between 56,000 and 85,000 miles. Fuel pumps from the 1995 and 1996 vehicles were sent to the vehicle manufacturer for analysis. The manufacturer determined that the two pumps failed because of severe corrosion of the positive brush shunt wire. According to the manufacturer, the corrosion is typical of previously observed field results during long-term exposure to gasoline containing reactive sulfur compounds that did not meet ASTM specifications. The manufacturer concluded that a high level of corrosion probably was present in both pumps at the start of the testing program, and the failures were unrelated to the use of Phase II RFG. The analysis submitted by the manufacturer is included as Appendix K. The third electric fuel pump, from the 1992 vehicle, was inadvertently disposed of by a fleet mechanic before it could be shipped to the manufacturer for analysis. While it seems likely that the third fuel pump suffered from the same corrosion as the other two, there is insufficient information to determine the cause of the failure.

In response to the findings in the manufacturer’s analysis, samples of the winter test and control fuels were analyzed to assess relative corrosivity. Some sulfur compounds that remain in gasoline after refining can have a corroding action on various metals. Copper strip corrosion tests were performed and the results showed both fuels to be non-corrosive. The results of the corrosivity tests support the manufacturer’s view that the electric pump failures were unrelated to the use of Phase II RFG.

The fourth fuel pump from the Elk Grove Village fleet was removed from a 1981 step van with 66,000 miles. The manufacturer’s analysis indicates that the mechanical pump is an after market part of unknown manufacture and showed no obvious signs of failure except an oil leak and extruded seal. The oil leak was not caused by fuel composition, but the extruded seal could be the result of excessive swell caused by oxygenates or a high aromatic content or a combination, or by an assembly problem. The manufacturer speculated that if the seal extruded because of excessive swell, that could have happened in the short duration of the test program; however, the manufacturer concluded it is more likely that the pump failure was unrelated to Phase II RFG use.

According to the Elk Grove Village fleet manager, the number of fuel pump failures during the test program is normal for the fleet’s size; in his experience, fuel pump replacement is expected on vehicles that have accumulated more than 60,000 miles. The fleet manager’s comments are included in Appendix L.

Houston

One fuel pump using test fuel in Houston failed during the course of the test program. That pump and three pumps from fleet vehicles not participating in the test program were sent to the manufacturer for analysis. All four pumps were from 1993 pickups with mileage ranging from 72,771 to 86,589. Heavy commutator wear coupled with normal brush wear led the manufacturer to believe that all four pumps failed due to operation on peroxidized fuel, also known as sour fuel. Since the failure occurred with both the test and control fuels, the manufacturer theorized that the failures are more likely related to the fuel dispensing system or to vehicle usage and operating factors rather than the composition of either fuel. The manufacturer's analysis is included in Appendix K.

The three pickups using Phase I RFG control fuel that had pump failures, described above, were not assigned to the control fleet. However, fleet personnel alerted EPA to the incidents. Although not assigned to the control fleet, the three pickups were using the same fuel as the control fleet. The incidents are reported here due to their close occurrence in time and similarity to the single test fleet fuel pump failure.

Fuel samples from both the test and control fuel dispensers in Houston were analyzed to determine their levels of peroxide, gum, and acidity, properties related to storage and handling degradation. Both fuel analyses indicated the fuel properties were within acceptable ranges. These analyses suggest that individual vehicle usage and operating factors are more likely related to the incidents than the fuel dispensing system, since peroxidation occurred in individual fuel tanks, not in the fleet's fuel dispensing system. The summer testing in Houston included an extended period of extremely hot weather, a condition conducive to oxidation of gasoline in individual vehicle fuel tanks.

Summary

There were six incidents during the course of the testing program in vehicles using test fuel. Five of the six incidents were deemed unrelated to the use of Phase II RFG by the relevant automobile manufacturer. In the sixth incident, the part in question was lost and the cause of its failure could not be determined.

No problems with starting, running, idling, acceleration, or power were reported by any fleet. One fleet manager described his fleet's use of Phase II RFG as transparent; fleet users and the mechanical staff saw no change or effect (see Appendix L).

IV. Fuel Economy

Another aspect of the testing program recommended by the workgroup involves measuring fuel economy with Phase II RFG compared to Phase I RFG. Two data sets are presented here.

A. Southwest Research Institute Study

EPA hired Southwest Research Institute (SWRI) to conduct a fuel economy study comparing Phase II RFG with Phase I RFG. Fuel economy was measured for 12 vehicles of various makes, ages, mileage, and fuel delivery systems. The vehicles were driven over fixed 50 mile urban and suburban routes. Fuel usage was determined by using a flow meter to precisely measure the total volume of fuel consumed during the 50 mile route. The Phase II RFG summer fuel oxygenated with MTBE was used. The results of this study do not indicate any statistically significant fuel economy difference between the fuels.

The fleet average fuel economy was 21.71 miles per gallon with Phase I RFG and 21.36 miles per gallon with Phase II RFG. The difference in fleet fuel economies was 0.343. Statistical tests indicate that the small difference in fleet fuel economies cannot be attributed to the fuel, and that the difference would have to be almost twice as large to be significant. The difference in fleet fuel economies may be due to variability in the test method. Sources of such test-to-test variability that could not be entirely controlled in the study include differences in driver inputs, traffic patterns, and weather effects.

The outcome of the SWRI study is consistent with other fuel economy studies, and with EPA's analysis of test fleet fuel economy (discussed below). Fuel economy is generally proportional to the energy content of the fuel. During the past few years, studies of the fuel economy effects of reformulated gasolines with oxygenates, including laboratory and on-road studies, have shown that the addition of two percent oxygen, by weight, to gasoline results in a one to three percent fuel economy loss. In this study, both gasolines have essentially the same oxygen content and the same energy content. Since the energy content difference between Phase I RFG and Phase II RFG is expected to be minimal, the absence of an impact on the fuel economy measured in this study was expected.

The SWRI study was designed to minimize the effects of the fuel economy variables that are normally present in driving. The key variables include differences in personal driving habits, weather (temperature, wind effects, and precipitation), traffic patterns (rush hour versus weekend, highway versus city driving), number of passengers, vehicle condition, and changes in tire pressure. The relative effect of many of these variables can be expected to exceed any reduction due to the use of RFG. The SWRI report is included as Appendix M. The report was reviewed by the technical steering committee and presented to the workgroup.

B. Fleet Average Fuel Economy

Data on fleet average fuel economy for this analysis is limited. The Boston fleet provided no data on fuel economy because the records of fuel usage were not sufficient. Data from the Houston fleet contained gaps and inconsistencies that prevented useful analysis. The Elk Grove Village fleet maintained sufficient fueling records to determine fuel economy for a portion of the fleet, and is included here.

Data obtained from the Elk Grove Village fleet for the test period in 1997 and 1998 indicate that there is no meaningful difference in fuel economy between Phase I RFG and Phase II RFG. For the Elk Grove Village fleet, vehicles using Phase I RFG as control fuel were different than those using Phase II RFG as test fuel, unlike the study performed by SWRI. Also, the routes and driving styles of each individual vehicle differed within each fuel group. Nevertheless, the makes and types of vehicles were essentially the same between each fuel group. The test fleet included seven Caprices and one E250. The control fleet included 12 Caprices, one Mustang, and one Tempo.

For the test period, March through July in 1998, the composite averages in miles per gallon (i.e., total fleet miles driven divided by total fleet gallons used) for the test and control fleets were 9.59 and 9.47 respectively, representing a 1.2 percent difference between the two fuels. The value of 1.2 percent does not represent a meaningful difference in miles per gallon between the two fuels, given the other measures of variability between the two data sets, noted above.

By comparison, during March through July in 1997, when both fleets were using Phase I RFG, the composite averages in miles per gallon for the test and control fleets were 9.48 and 9.47 respectively, representing a 0.1 percent difference between the two fuels. The 95 percent confidence interval for the 1997 control fleet was 9.32 to 11.29 miles per gallon. The mean miles per gallon for the individual vehicles in the test fuel fleet (as opposed to a composite average) was 9.33 miles per gallon, which lies within the confidence interval for the control fleet.

V. Nonroad Test Program

In addition to vehicle testing, the workgroup recommended a testing program to evaluate the performance of Phase II RFG with nonroad engines. The test fuel used for nonroad engine testing was the same as the test fuel used with vehicle fleets. The nonroad test program included 177 pieces of gasoline-powered equipment that encompassed 11 types of utility, lawn, and garden equipment, and included both two-cycle and four-cycle engine designs. In addition, two-cycle and four-cycle marine engines were tested by Mercury Marine at six sites.

A. Utility, Lawn, and Garden Equipment

The Arlington County, Virginia Department of Parks and Natural Resources provided the equipment and resources to evaluate utility, lawn, and garden equipment. Their equipment fleet consisted of 177 units ranging from three horsepower handheld trimmers to 17 horsepower tractors, with both two-cycle and four-cycle engine designs.

The engines listed in the following table were used for in use testing of Phase II RFG. Most of the engines are used in brush cutters, mowers, gas-powered hedge trimmers, chainsaws, backpack leaf blowers, generators, rototillers, edgers, vacuum blowers, and pruners, and had horsepower ratings between three and eight. Four units are small tractors with horsepower ratings between 12 and 17. Eighteen of the 177 units meet EPA's emission regulations for small handheld engines (40 CFR 90); all 18 units were manufactured by Stihl.

Table 5 - Arlington County Nonroad Engines

Number of Units	Engine Make	Engine Type
60	Stihl	two-cycle
35	Kawasaki	two-cycle
30	Briggs and Stratton	four-cycle
25	Tecumseh	four-cycle
15	Honda	four-cycle
4	Tanaka	two-cycle
4	Yamaha	two-cycle
4*	Kohler	four-cycle

* Tractors

The test fuel for this equipment was the summer fuel oxygenated with MTBE. The fuel was delivered on August 28, 1998 to a storage tank at the County water treatment plant. To aid equipment refueling, a pickup truck was used as a mobile fueling station. A 100 gallon fuel tank in the back of the truck was used to fuel two-cycle engines, and six five-gallon cans were used to fuel four-cycle engines. The truck tank and cans were refilled at the main storage tank as necessary. Each refill of the 100 gallon tank included the addition of two-cycle engine oil at a gasoline/oil ratio of 40 to one. During the test period, Quaker State Itasca two-cycle engine oil was used.

The performance testing consisted of fueling the engines with Phase II RFG and operating them normally. The fuel was replenished as needed. Any performance problems encountered were to be reported. The testing period began on September 1 and continued until the test fuel was expended during the third week in November. The amount of use for each piece of equipment was not recorded. The primary activities during the testing period consisted of lawn maintenance, leaf removal, and ball field maintenance.

During the testing period, 185 gallons of Phase II RFG were consumed. Assuming a maximum fuel consumption rate of about one-half gallon per hour, testing consisted of more than 370 hours of operation.

No performance-related incidents occurred during the test period. The equipment supervisor reported that there were no perceptible changes in engine performance and no indications of leaks.

B. Marine Engines

Approximately 3,800 gallons of summer fuel oxygenated with MTBE were provided to four Mercury Marine testing facilities in Wisconsin, Florida, and Oklahoma, and two materials testing locations in Illinois and North Carolina. The engines tested ranged from small two-cycle, 25 horsepower outboard engines to large four-cycle, 500 horsepower inboard and stern drive engines.

Small two-cycle outboard engines were tested for startability and running quality, with storage at cool temperatures. Cool temperatures were those lower than are typical for summer fuel. The field testing in November 1998 in Wisconsin with summer fuel captured the temperature conditions that are characterized as the fall shoulder season. Testing consisted of start-up, warm-up, idle quality, and running quality phases. The engines were mounted on a dock for the four-phase test and then moved to an outdoor storage rack for 40 hours to stabilize at ambient conditions, in a temperature range of 35 to 55 degrees. The engines were then returned to the dock and startability testing was conducted. No performance problems with Phase II RFG were reported.

In addition to field testing, engine dynamometer testing was conducted with two-cycle outboard engines. A dynamometer is a device that simulates the resistance the engine would experience under normal operating conditions. The dynamometer tests measured the maximum power produced using the summer test fuel and a baseline fuel known as indolene. No noticeable difference in operating performance was found.

Large four-cycle engines were also tested using both test and baseline fuels. The tests measured power output using an engine dynamometer and found no significant difference between the fuels.

Testing of fuel system materials was done by Airtex and Magnetti Morelli. Gaskets and other fuel system materials were tested. No detrimental effects were reported.

VI. Motorcycle Test Program

Over 1,700 gallons of summer fuel oxygenated with MTBE were provided to Harley-Davidson for laboratory testing of six current model motorcycles, on-road performance testing of six privately-owned motorcycles, and materials compatibility testing. The Harley-Davidson motorcycles listed in the following table were used for laboratory testing of Phase II RFG.

Table 6 - Harley-Davidson Motorcycles Tested in Laboratory

Number	Year	Model	Engine (cc)	Fuel System
2	1997	Sportster	1200	Carburetor
2	1998	FLT/HT	1450	Carburetor
2	1998	FLT/HT	1450	Fuel Injection

The laboratory testing consisted of performance tests on six motorcycles using the test fuel and a baseline fuel known as indolene. Testing was conducted using a chassis dynamometer, a device that allows the motorcycle to remain stationary while the rear wheel turns a drum that provides resistance to simulate the resistance of the motorcycle and rider on the highway. The rider operates the motorcycle as though it were on the highway by shifting gears and adjusting the throttle to follow a graph on a video screen. Acceleration, driveability, and startability were evaluated during these tests. No significant difference in performance was observed between the baseline fuel and Phase II RFG.

On-road testing was conducted by Harley-Davidson employees on their own Harley-Davidson motorcycles. The Harley-Davidson motorcycles listed in the following table were used for on-road testing of Phase II RFG.

Table 7 - Harley-Davidson Motorcycles Tested On-road

Year	Model ID	Model Name	Type	Engine (cc)	Starting Odometer	Accumulated Miles
1998	FLHT	Electra Glide	Touring	1450	675	1575
1998	FLHTC	Electra Glide Classic	Touring	1450	12500	1200
1998	FLHTCUi	Ultra Classic	Touring	1450	1300	500
1998	FLTR	Road Glide	Touring	1450	9000	2500
1998	FLTRI	Road Glide	Touring	1450	2000	700
1999	FLTR	Road Glide	Touring	1450	150	500

The test period with the summer test fuel was from mid-October until the end of November in the Milwaukee, Wisconsin area, although summer fuel is not provided to retail stations after September 15. The daily temperatures for the on-road testing period are listed in Appendix N. Performance was evaluated using both the test fuel and a commercially available fuel. No performance problems with Phase II RFG were reported.

Materials compatibility tests were done on three sets of fuel system elastomer components. An independent laboratory tested the components by soaking them in both the test fuel and a baseline gasoline and then measuring size changes. Paint finish and decal compatibility tests were also performed using the test fuel and a baseline fuel. Finished fuel tanks were placed in an outdoor rack and each fuel was periodically spilled over a tank during a period of three weeks to determine the effect. No detrimental effects were identified.

VII. Conclusion

All available data indicate that consumers should experience no difference in performance or fuel economy when Phase II RFG replaces Phase I RFG.

EPA tested in use vehicles in three cities over a period of three to five months. The combined test fleet drove over one million miles with Phase II RFG. Out of a combined fleet of 374 vehicles, six component-related incidents occurred during the course of the testing program. Five of the six incidents were deemed unrelated to the use of Phase II RFG by the relevant automobile manufacturer. In the sixth incident, the part in question was lost and the cause of its failure could not be determined.

No problems with starting, running, idling, acceleration, or power were reported by any fleet. One fleet manager described his fleet's use of Phase II RFG as transparent; fleet users and the mechanical staff saw no change or effect (see Appendix L).

Studies have shown that incident rates increase with vehicle mileage, irrespective of the fuel used. Vehicle maintenance is the key to good performance with any fuel.

In a separate study, SWRI compared fuel economy with Phase II RFG to Phase I RFG. Fuel economy was measured for 12 vehicles of various makes, ages, mileage, and fuel delivery systems. The vehicles were driven over fixed 50 mile urban and suburban routes. Fuel usage was determined by using a flow meter to precisely measure the total volume of fuel consumed during the 50 mile route. The results of this study do not indicate any statistically significant fuel economy difference between the fuels.

The outcome of the SWRI study is consistent with other fuel economy studies, and with EPA's analysis of test fleet fuel economy. Fuel economy is generally proportional to the energy content of the fuel. During the past few years, studies of the fuel economy effects of reformulated gasolines with oxygenates, including laboratory and on-road studies, have shown that the addition of two percent oxygen, by weight, to gasoline results in a one to three percent fuel economy loss. In this study, both gasolines have essentially the same oxygen content and the same energy content. Since the energy content difference between Phase I RFG and Phase II RFG is expected to be minimal, the absence of an impact on the fuel economy measured in this study was expected.

The Arlington County, Virginia Department of Parks and Natural Resources provided the equipment and resources to evaluate utility, lawn, and garden equipment. Their equipment fleet consisted of 177 units ranging from three-horsepower handheld trimmers to 17-horsepower tractors with both two-cycle and four-cycle engine designs. Testing began September 1 and concluded the third week in November. During the testing period, 185 gallons of Phase II RFG were consumed. Assuming a maximum fuel consumption rate of about one-half gallon per hour, testing consisted of more than 370 hours of operation. No performance-related incidents occurred during the test period. The equipment supervisor reported that there were no perceptible changes in engine performance and no indications of leaks.

Performance and materials testing was conducted with motorcycles by Harley-Davidson and with marine engines by Mercury Marine. In both cases, outdoor testing in Wisconsin occurred in the autumn with summer test fuel, capturing shoulder season effects. The results indicate no performance problems with Phase II RFG.

In summary, no difference in vehicle performance or fuel economy is expected when Phase II RFG replaces Phase I RFG. In addition, no difference in performance is expected with small engines, marine engines, or motorcycles.