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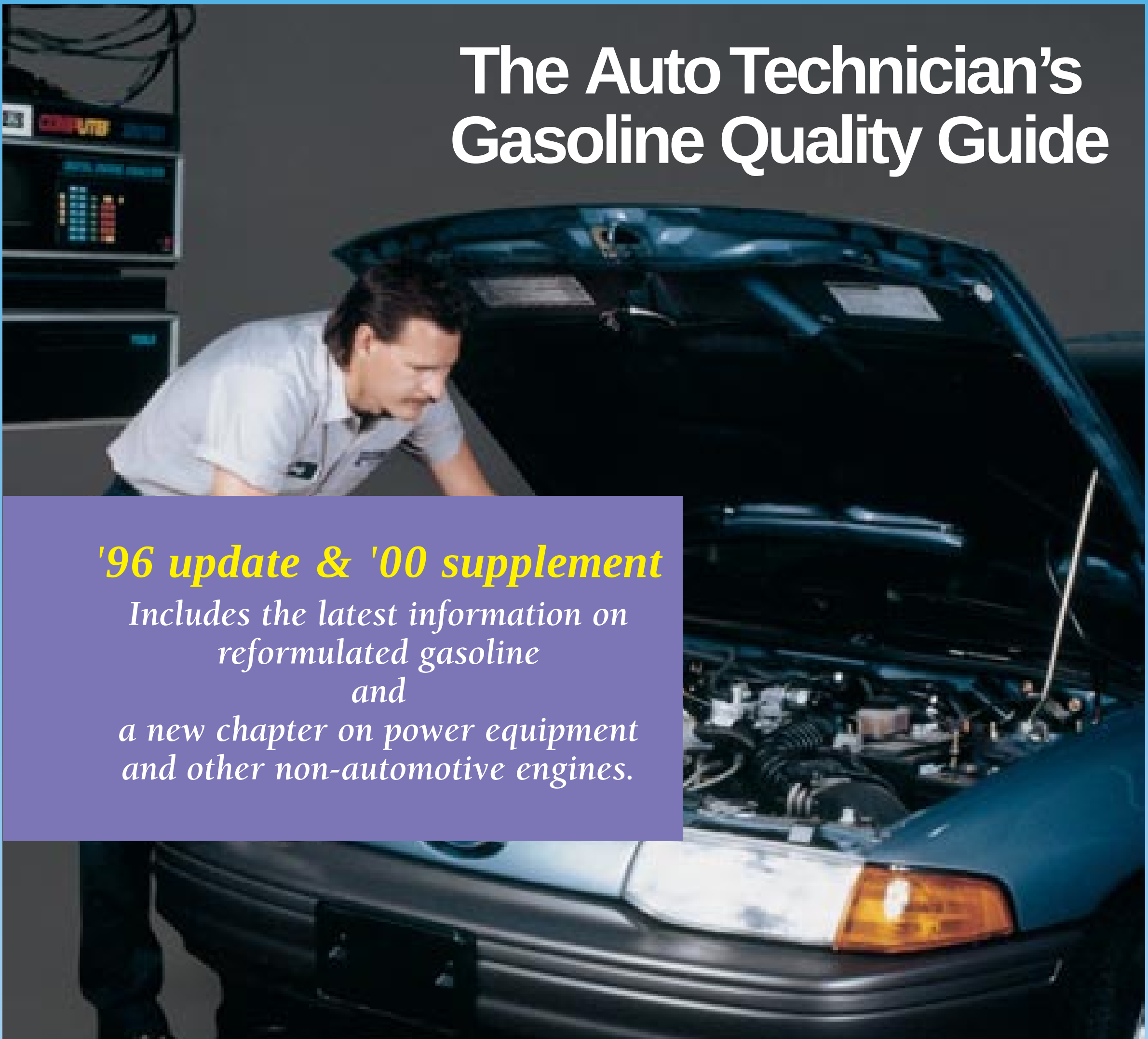
Changes in Gasoline III



The Auto Technician's Gasoline Quality Guide

'96 update & '00 supplement

Includes the latest information on reformulated gasoline and a new chapter on power equipment and other non-automotive engines.

Fuel Specifications, Octane Quality, and Fuel Volatility and How They Affect Vehicle Performance

Changes in Gasoline Due to Government Regulations

Oxygenated Fuels and Reformulated Gasoline

Power Equipment and Non-Automotive Engine Issues

Fuel Systems Deposits and Detergents/Deposits Control Additives

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Changes in Gasoline III is the latest in the ongoing series of Changes in Gasoline manuals. The first manual, entitled *Changes in Gasoline & the Automobile Service Technician,* was originally published in 1987. Over a four year period it was periodically updated to focus on fuel related areas of greatest interest to automobile service technicians. The first version of the manual achieved a circulation of 345,000 copies.

The Clean Air Act Amendments of 1990 dictated that a number of changes be made to gasoline to reduce its impact on the environment. The gasoline related requirements of the Clean Air Act Amendments take place over a number of years. Some of the most significant requirements such as the oxygenated fuel programs in carbon monoxide non-attainment areas were implemented in 1992. At that time a new manual entitled *Changes in Gasoline II – The Auto Technician's Gasoline Quality Guide* was released. Changes in Gasoline II has now achieved a circulation of 105,000 copies. The "Changes in Gasoline" manuals have been used in the automotive training courses of hundreds of technical colleges as well as numerous commercial training centers. Several auto manufacturers also use the manual for various purposes including their training programs.

Still more changes in gasoline occurred in 1995 when several ozone non-attainment areas were required to introduce reformulated gasoline for the first time.

In some areas where reformulated gasolines were introduced there was a lot of confusion and accurate concise information was not always available for the auto service professional. This information void prompted us to undertake yet another complete rewrite of the Changes in Gasoline manual to ensure that service technicians have the information they need on these and other changes that are occurring to gasoline. We are very pleased to introduce you to the result of that effort — *Changes in Gasoline III–The Auto Technician's Gasoline Quality Guide*.

In this new version of the manual we continue our tradition of presenting information about gasoline quality as it relates to vehicle performance and driveability. Every attempt is made to focus on the auto technician's areas of interest and to cover current topics. A new chapter concerning fuel issues for power equipment and recreational engines has also been added because of increased interest in this subject.

We encourage you to read on and see why nearly a half million auto service professionals have chosen the "Changes in Gasoline" manual series as their definitive reference source for information on gasoline quality and its relationship to vehicle performance.

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Changes in Gasoline III

The Auto Technician's Gasoline Quality Guide

Introduction

For a number of years there has been an ever-growing body of governmental regulations to address concerns about the environment and energy security. Many of these regulations have been aimed at minimizing the environmental impact of the automobile. Most regulations have focused on the automobile and have resulted in automotive technology which significantly reduces vehicle emissions compared to pre-control levels. In fact, compared to pre-control era automobiles, carbon monoxide (CO) and hydrocarbon (HC) tailpipe emissions have been reduced by 96%, while emissions of oxides of nitrogen (NO_x) have been reduced by 76%.

With this type of progress already achieved via automotive technology, it was apparent that if further gains were to be made, it would be necessary to focus on cleaning up the fuels that these vehicles use.

Of course, compositional change to gasoline is not something new. Refiners have, over the years, altered the composition of gasoline in response to technological advancements and changes in demand for end use products. However recent compositional changes have been, and will continue to be, driven by environmental considerations.

The first such change was the wide-scale introduction of unleaded gasoline in the early 1970s followed by the phase-down of lead levels in leaded gasoline (1975-1985). This was followed by Phase I of the U.S. Environmental Protection Agency's (EPA) fuel volatility regulations (1989). Further reductions in fuel volatility were achieved in 1992 under Phase II of these regulations. These programs have all resulted in compositional changes to gasoline.

In the late 1980s several areas of the U.S. implemented oxygenated fuel mandates to reduce CO emissions. Such areas included various cities and towns in Colorado, Nevada, Arizona, New Mexico, and Texas. These programs required the sale of oxygenated fuels in certain winter months. Oxygenated fuels contain ethanol, methyl tertiary butyl ether (MTBE) or other oxygen-bearing compounds. Oxygenates chemically enlean the air/fuel mixture resulting in more complete combustion and lower CO emissions.

In 1990, Congress passed, and the President signed, the 1990 Clean Air Act Amendments. These amendments represent the most comprehensive clean air legislation in history. Title II of these amendments required further environmentally driven changes in gasoline.

In the fall of 1992, over thirty-five areas of the nation failing to meet the federal standard for CO were required to implement oxygenated fuel programs similar to those in the areas mentioned above.

There were also requirements addressing ozone non-attainment that took effect in 1995. These regulations required the introduction of "reformulated gasoline" in the nine worst ozone non-attainment areas. The regulations also contained provisions for other ozone non-attainment areas to "opt in" to the program.

Clearly the addition of oxygenates and reformulation of gasoline have led to further compositional changes in gasoline. Each compositional change in gasoline, whether driven by efforts to increase production, improve octane quality, or improve the environment, has advantages and disadvantages at the refinery as well as in the automobile.

While these regulations set specifications to control the environmental impact of gasoline, there are also specifications and guidelines to control the performance characteristics of gasoline to ensure that it performs satisfactorily. Such guidelines are usually based upon American Society for Testing & Materials (ASTM) standards. As more and more changes occur in the composition of gasoline, it becomes increasingly difficult to balance environmental specifications against performance based specifications and guidelines.

A former General Motors executive, Alfred P. Sloan, recognized that, for automotive scientists and engineers "The central problem…has been to develop a more satisfactory relationship between the fuel and the engine." That statement's validity continues today. While Mr. Sloan's comments focused on the problems of scientists and engineers, it is important to recognize that you, the auto service technician, must deal with such factors on a day-to-day basis, face to face, with the consumer.

Increasingly, the consumer turns to the auto service technician for fuel related advice. Consumers seek their opinion on what type of fuel to use and on the selection of gasoline additives. Yet, it is often difficult for the auto service technician to obtain factual information on these topics. Only a few years ago this information was considered "nice to know" but not "need to know." That has changed and it is important for today's auto technician to understand fuel quality issues, both for diagnostic reasons and for the ability to convey accurate information and recommendations to the consumer.

The purpose of this manual is to aid you in that endeavor. Fuel specifications and their importance are covered. Changes in gasoline composition, fuel oxygenates, and reformulated gasoline are discussed in detail. The impact of government regulations on gasoline composition and quality are detailed as are numerous other topics. Since the first edition of "Changes in Gasoline" (1987), we have constantly updated the format and content of the manual to keep up with current interests. To that end this edition contains expanded information on reformulated and oxygenated gasolines. We have also added a chapter on the use of these fuels in power equipment and recreational products.

Designed to separate fact from fiction, this manual is based on research work and technical papers, primarily from the automotive and petroleum industries. It is designed to aid you in diagnosing fuel related problems and also to assist you in explaining them to the auto owner. Auto salespersons and other auto professionals may also find this manual helpful in discussing fuel-related matters with consumers.

This manual was funded in part by an educational grant from the Renewable Fuels Foundation, a non-profit organization that provides educational materials on renewably derived fuels. Realizing that the auto service technician is not often furnished with condensed, concise and technically accurate information on fuel quality, the Renewable Fuels Foundation felt that this manual would help fill an informational void.

It is our sincere hope that this information will be useful to you and we urge you to keep this manual as a reference for continued use in your operation.

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Specifications & Standards

In order to understand fuel quality standards and how they affect the automobile, it is important to have a basic understanding of gasoline, how and why quality standards are set, and what significance they have on the driveability, performance and durability of an automobile engine and related systems.

Gasoline is not a single substance. It is a complex mixture of components which vary widely in their physical and chemical properties. There is no such thing as pure gasoline. Gasoline must cover a wide range of operating conditions, such as variations in fuel systems, engine temperatures, fuel pumps and fuel pressure. It must also cover a variety of climates, altitudes, and driving patterns. The properties of gasoline must be balanced to give satisfactory engine performance over an extremely wide range of circumstances. In some respects, the prevailing quality standards represent compromises, so that all the numerous performance requirements may be satisfied.

By properly controlling specifications and properties, it is possible to satisfy the requirements of the hundreds of millions of spark ignition engines in the marketplace with just a few grades of gasoline.

The most commonly used gasoline quality guidelines are established by the American Society for Testing and Materials (ASTM). ASTM specifications are established by consensus based on the broad experience and close cooperation of producers of motor gasoline, manufacturers of automotive equipment, users of both commodities, and other interested parties such as state fuel quality regulators.

ASTM Standards are voluntary compliance standards. However, the United States Environmental Protection Agency (EPA) and some states have passed regulations and laws which, in some cases, require gasoline to meet all, or a portion of, the ASTM gasoline guidelines.

Currently, ASTM D 4814 is the standard specification for automotive spark ignition engine fuel. There are several test methods encompassed in the D 4814 specification. It should also be noted that in addition to ASTM standards, some petroleum companies and pipeline operators may have specifications which go beyond the ASTM guidelines. For instance, some refiners may specify a higher minimum motor octane or use of a specific deposit control additive.

Recently more attention has been focused on the environmental requirements that gasoline must meet. However even with adjustments in composition to comply with environmental standards, gasoline should still meet the performance standards established by ASTM.

This chapter addresses ASTM specifications and other fuel quality parameters and their importance.

Octane Quality and Vehicle Octane Requirement

Gasolines are most commonly rated based on their Antiknock Index (AKI), a measure of octane quality. The AKI is a measure of a fuel's ability to resist engine knock (ping). The AKI of a motor fuel is the average of the Research Octane Number (RON) and Motor Octane Number (MON) or (R+M)/2. This is also the number displayed on the black and yellow octane decal posted on the gasoline pump. Optimum performance and fuel economy is achieved when the AKI of a fuel is adequate for the engine in which it is combusted. There is no advantage in using gasoline of a higher AKI than the engine requires to operate knock-free.

The RON and MON of fuels are measured by recognized laboratory engine test methods. Results of these tests may generally be translated into approximate field performance.

In general, the RON affects low to medium speed knock and engine run-on or dieseling. If the Research Octane Number is too low, the driver could experience low speed knock and engine run-on after the engine is shut off.

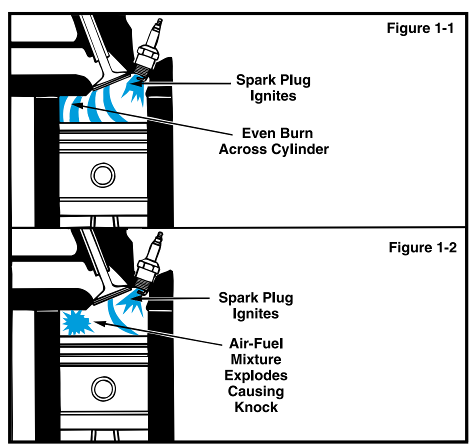
The MON affects high speed and part-throttle knock. If the Motor Octane Number is too low, the driver could experience engine knock during periods of power acceleration such as passing vehicles or climbing hills.

The antiknock performance of a fuel, in some vehicles, may be best represented by the RON, while in others it may relate best to the MON. Extensive studies indicate that, on balance, gasoline antiknock performance is best related to the average of the Research and Motor Octane Numbers, or (R+M)/2. This formula is continuously reviewed for its accuracy in predicting gasoline performance in new automobiles.

The RON of a fuel is typically 8 to 10 numbers higher than the MON. For instance, an 87 octane gasoline typically has a MON of 82 and a RON of 92.

Most vehicles give satisfactory performance on the recommended octane-rated fuel. But in some cases, using the fuel specified will not guarantee that a vehicle will operate knock-free, even when properly tuned. There can be signifi-

Figure 1-1, 1-2 Proper Combustion vs. Source of Engine Knock



Illustrations courtesy of AAVIM, Athens, Georgia

In an engine of a given compression ratio, each grade of gasoline has a limit to how much it can be compressed and still burn evenly, supplying a smooth even thrust to the piston (Figure 1-1). But when the AKI or octane quality of a gasoline is insufficient for the engine's compression ratio, it burns unevenly and causes the engine to knock (Figure 1-2). The spark-ignited flame progresses rapidly across the combustion chamber. Heat and pressure build up on the unburned fuel to the left of the flame front. Instead of continuing to burn smoothly and evenly, the unburned portion of the air/fuel mixture explodes violently from spontaneous combustion.

Table 1-1
Factors Affecting Octane Number Requirement

Design/Operating Factors	In Use Conditions
Compression Ratio	Barometric Pressure/ Altitude
Ignition Timing	Temperature
Air Fuel Ratio	Humidity
Combustion Temperature -intake manifold heat input -inlet air temperature -coolant temperature	Combustion Chamber Deposits
Exhaust Gas Recirculation Rate	
Combustion Chamber Design	

cant differences among engines, even of the same make and model, due to normal production variations.

The actual loss of power and damage to an automobile engine, due to knocking, is generally not significant unless the intensity becomes severe. Heavy and prolonged knocking, however, may cause damage to the engine.

Whether or not an engine knocks is dependent upon the octane quality of the fuel and the Octane Number Requirement (ONR) of the engine. The ONR is affected by various engine design factors and in-use conditions. (See Table 1-1)

Engines experience increased octane number requirement when the ignition timing is advanced. The air/fuel ratio also effects ONR with maximum octane requirement occurring at an air/fuel ratio of about 14.7:1. Enriching or enleaning from this ratio generally reduces octane requirement. Combustion temperatures are also a factor with higher combustion temperatures increasing ONR. Therefore, intake manifold heat input, inlet air temperature, and coolant temperature have an indirect affect on octane requirement. Additionally the Exhaust Gas Recirculation (EGR) rate can affect ONR.

Combustion chamber design affects octane requirements. However the effect of various designs is difficult to predict. In general, high swirl (high turbulence) combustion chambers reduce ONR, thus permitting the use of higher compression ratios. The compression ratio itself is one of the key determinants of octane requirement. As compression ratio increases, so does the need for greater octane levels (Figure 1-3).

Excessive combustion chamber deposits can increase the octane requirement of an engine due to increased heat retention and increased compression ratio.

There are also atmospheric and climatic factors which influence ONR. Increases in barometric pressure or temperature increase octane requirement. Increases in humidity will lower octane requirements. Octane requirements decrease at higher altitudes due to decreases in barometric pressure.

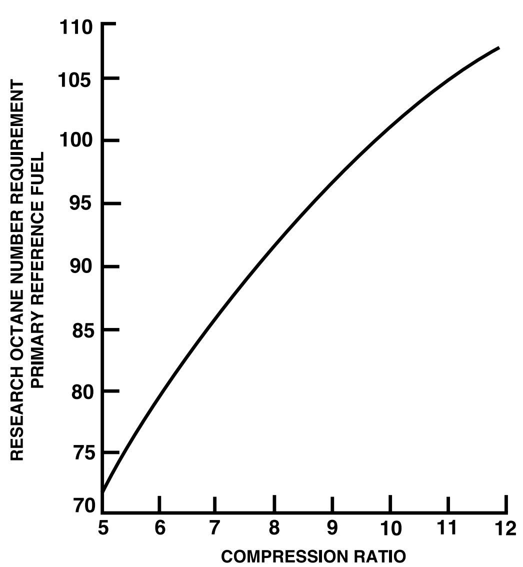
Many of the variables related to octane and octane requirement can be totally or partially compensated for by the engine control systems in most late model vehicles. For instance, vehicles equipped with knock sensor devices allow the engine control system to advance or retard the ignition timing in response to engine knock. Other vehicles with electronic engine controls employ the use of a barometric (baro) sensor to compensate spark timing and air/fuel mixture in response to barometric changes. The effect of altitude on octane requirement in these late model vehicles is about one-third that of engines not so equipped.

A number of myths about octane have grown over the years. There is a widespread perception that the greater the octane the better the performance. However, once enough octane is supplied to prevent engine knock, there is little, if any, performance improvement. One exception to this would be in vehicles equipped with knock sensors. In these vehicles, if octane is insufficient, the computer will retard the timing to limit engine knock. If the vehicle is operating in the "knock limiting" mode (retarded timing), using a higher octane fuel will allow timing to be advanced, resulting in some level of performance increase. However, even in these vehicles, tests have shown that there is no perceptible performance improvement from using a fuel of higher octane than that recommended by the vehicle manufacturer.

Another myth is that using a higher octane fuel will result in improved fuel economy (increased miles per gallon). Octane is nothing more than a measure of anti-knock quality. Fuel economy is determined by a number of variables including the energy content of the fuel. Some premium grades of fuel may contain components which increase energy content. In those cases, fuel economy may improve slightly as a result of higher energy content, but not as a result of the higher octane. Two fuels of identical octane could have different energy content due to compositional differences.

Consumers need only use a gasoline meeting the vehicle manufacturer's recommended octane levels. If engine knocking occurs on such fuels and mechanical causes have been eliminated, then the consumer should purchase the next highest octane gasoline (above the manufacturer's recommendation in the owners manual) that will provide knock-free operation.

Figure 1-3
Compression Ratio vs. Octane Requirement



As compression ratio increases, the octane requirement of an engine increases. This is one of the primary considerations of engine design.

Volatility

Gasoline is metered in liquid form, through the fuel injectors (or carburetor), and mixed with air and atomized before entering the cylinders. Therefore, it is very important that a fuel's tendency to evaporate is controlled to certain standards. A fuel's ability to vaporize or change from liquid to vapor is referred to as its volatility. Volatility is an extremely important characteristic of gasoline and has an effect on the areas listed in Table 1-2.

Table 1-2
Effects of Gasoline Volatility on Vehicle Performance

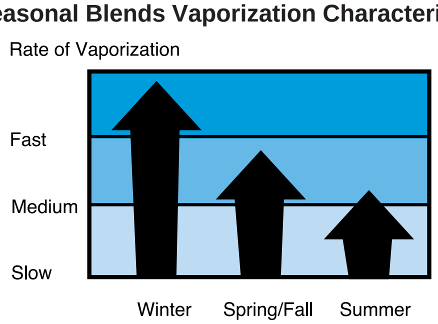
Volatility Too Low	Volatility Too High
Poor cold start	High evaporative emissions/ Canister overload & purge
Poor warm up performance	Hot driveability problems/ vapor lock
Poor cool weather driveability	Fuel economy may deteriorate
Increased deposits -crankcase -combustion chamber -spark plugs	
Unequal fuel distribution in carbureted vehicles	

Gasoline which is not volatile enough (a common occurrence in the 1960s) results in poor cold start and poor warm up driveability as well as unequal distribution of fuel to the cylinders in carbureted vehicles. These fuels can also contribute to crankcase and combustion chamber deposits as well as spark plug deposits.

Gasoline which is too volatile (typical of the mid 1980s), vaporizes too easily and may boil in fuel pumps, lines or in carburetors at high operating temperatures. If too much vapor is formed, this could cause a decrease in fuel flow to the engine, resulting in symptoms of vapor lock, including loss of power, rough engine operation, or complete stoppage. Fuel economy could also deteriorate and evaporative emissions could increase.

In order to assure that fuels possess the proper volatility characteristics, refiners adjust gasoline seasonally (see Figure 1-4), providing more volatile gasoline in the winter to provide good cold start and warm up performance. In the summer, gasoline is made less volatile to minimize the incidence of vapor lock and hot driveability problems and to comply with environmental standards. Adjustments are also made for geographic areas with high altitudes. This is done because it requires less heat for a liquid to boil at higher altitudes.

Figure 1-4
Seasonal Blends Vaporization Characteristics



Fuels are blended to meet seasonal and local needs. For winter, a greater portion of fuel components are the fast-vaporizing type. For summer use, more of the fuel components are the slower vaporizing type.

While these seasonal and geographic changes in standards for volatility minimize problems, they do not completely eliminate them. For example, during spring and fall, a gasoline volatility suitable for lower temperatures may experience problems due to unseasonably warm weather.

There are three parameters used to control volatility limits. Vapor pressure, distillation, and vapor liquid ratio. ASTM provides standards for the test procedures to measure these characteristics. There are six vapor pressure/distillation classes of gasoline designated AA, A, B, C, D, and E. AA is the least volatile while E is the most volatile. The AA volatility class was recently added to reflect EPA fuel volatility regulations. There are also six Vapor Lock Protection Classes numbered 1 through 6 with 1 being the least volatile and 6 being the most volatile (see Table 1-3 next page). A Vapor Pressure/ Distillation Class and a Vapor Lock Protection Class are specified for each state (or areas of a state) by month.

Vapor-Liquid Ratio is a test to determine the temperature required to create a Vapor-Liquid (V/L) ratio of 20. More volatile fuels require lower temperatures to achieve the ratio while less volatile fuels require higher temperatures to create the same ratio. V/L ratio assists in defining a fuel's tendency to contribute to vapor lock.

The Vapor Pressure Test can be performed by a variety of laboratory procedures and automated measurement devices. One test procedure, referred to as the "Reid Method" is performed by submerging a gasoline sample (sealed in a metal sample chamber) in a 100°F water bath. More volatile fuels will vaporize more readily, thus creating more pressure on the measurement device and higher readings. Less volatile fuels will create less vapor and therefore give lower readings. The vapor pressure measurement from the Reid test method is referred to as Reid Vapor Pressure or RVP. Because of the earlier popularity of this test method, the term RVP has become a widely used term when referring to vapor pressure. However, the "Reid" in Reid Vapor Pressure merely designates the method used to determine the vapor pressure or VP. As other test procedures become more popular, the term RVP is being dropped in favor of vapor pressure or VP.

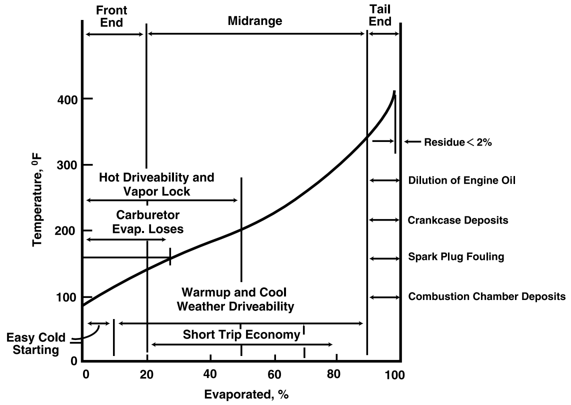
Service bulletins and trade publications often refer to vapor pressure or RVP and it is the volatility parameter most familiar to service technicians.

However it is important to note that it is one of only three tests for monitoring and controlling fuel volatility.

The V/L ratio and vapor pressure tests are measurements of a fuel's "front end volatility," or more volatile components, which vaporize first.

The distillation test is used to determine fuel volatility across the entire boiling range of gasoline. Gasoline consists of a variety of chemical components that evaporate at different temperatures. More volatile components (faster vaporizing) evaporate at lower temperatures, less volatile (slower vaporizing) ones at higher temperatures. The plotting of these evaporation temperatures is referred to as a distillation curve (Figure 1-5). The ASTM specification sets temperature ranges at which 10%, 50%, and 90% of the fuel will be evaporated as well as at what temperature all the fuel has evaporated (referred to as end point). Each point affects different areas of vehicle performance.

Figure 1-5
Importance of Proper Distillation



Gasoline significantly below the curve (increased volatility) would provide easier starting, better warm-up and be less likely to contribute to deposits but would have higher evaporative losses and be more likely to contribute to vapor lock.

Gasoline significantly above the curve (decreased volatility) would have fewer evaporative losses and be less likely to vapor lock. Also, short trip economy would improve. However, ease of starting and warm up would suffer and deposits and dilution of engine oil could increase. Exhaust emissions may also increase in some cases.

The 10% evaporated temperature must be low enough to provide easy cold starting but high enough to minimize vapor lock/hot driveability problems. The 50% evaporated temperature must be low enough to provide good warm up and cool weather driveability without being so low as to contribute to hot driveability and vapor locking problems. This portion of the gallon also effects short trip economy. The 90% and end point evaporation temperatures must be low enough to minimize crankcase and combustion chamber deposits as well as spark plug fouling and dilution of engine oil.

Distillation characteristics are frequently altered depending on the availability of gasoline components. This should not alter performance characteristics of the gasoline unless the alteration is severe. Depending on the distillation class, 10% of the fuel would be evaporated prior to reaching a temperature of 122°F to 158°F, fifty percent prior to reaching a temperature of 150°F to 250°F (ASTM recently voted to change the lower limit of the fifty percent evaporation range for volatility classes D and E, from 170˚F to 150˚F. This change will be reflected in future editions of the ASTM standards.) and ninety percent prior to reaching a temperature of 365°F to 374°F. All of the fuel should be evaporated by 437°F. The ranges between these temperatures provide for adjustment in volatility classes to meet seasonal changes.

The parameters of the six vapor pressure/distillation classes are covered in Table 1-3. During the EPA volatility control season (June 1 to September 15 at retail) gasoline vapor pressure is restricted to 9.0 psi or 7.8 psi depending upon the area. The 7.8 psi requirement is generally for southern ozone non-attainment areas. The EPA summertime volatility regulations permit gasoline-ethanol blends containing 9 volume percent to 10 volume percent ethanol to be up to 1.0 psi higher in vapor pressure than non-blended gasoline.

It should also be noted that the volatility parameters in Table 1-3 apply to conventional gasoline. As discussed in Chapter 2, reformulated gasoline has requirements for even lower vapor pressure during the EPA volatility control season.

Other Fuel Specifications

While octane and volatility are the most important standards relating to driveability there are other fuel standards covered by ASTM guidelines. Table 1-4 lists the various specifications and their importance. A copper corrosivity standard ensures that the fuel will not create excessive corrosion in the vehicle fuel system. Stability standards are controls of a fuel's tendency to contribute to induction system deposits and filter clogging as well as determining the fuel's storage life.

A limitation is placed on sulfur content. Excessive sulfur content can increase exhaust emissions and engine deposits. Additionally, excessive sulfur can lead to acidic compounds in the crankcase which reduce the effectiveness of engine oil additives, thereby contributing to premature engine wear. There is a specification for the maximum lead content in

Table 1-3
ASTM D 4814 GASOLINE VOLATILITY REQUIREMENTS

Vapor Pressure/ Distillation Class	Distillation Temperatures °F				Vapor Pressure psi/Max.	Vapor Lock Protection Class	Temp. for Vapor-Liquid Ratio of 20 °F/Min.
	10% Evap. Max.	50% Evap.	90% Evap. Max.	End Point Max.			
AA	158	170-250	374	437	7.8	1	140
A	158	170-250	374	437	9.0	2	133
B	149	170-245	374	437	10.0	3	124
C	140	170-240	365	437	11.5	4	116
D	131	150-235	365	437	13.5	5	105
E	122	150-230	365	437	15.0	6	95

ASTM D 4814 recommends a vapor pressure/distillation class and vapor lock protection class for each state (or in some cases a portion of a state) by calendar month. Between June 1st and September 15th of each year, the Vapor Pressure of gasoline sold at retail must comply with EPA volatility regulations which require an RVP of 9.0 psi (or 7.8 psi in the case of many ozone non-attainment areas). EPA regulations permit ethanol blends (containing 9 volume % to 10 volume % ethanol) to exceed the above referenced vapor pressures by up to 1.0 psi. These standards apply to conventional gasoline and oxygenated fuels. Reformulated gasoline has more stringent requirements for vapor pressure during the summertime volatility control season.

Table 1-4
Gasoline Specifications and Their Importance

Specification	**Importance**
Antiknock Index (AKI)	
Research Octane Number (RON)	Low to medium speed knock and run-on
Motor Octane Number (MON)	High speed knock/Part-throttle knock
Fuel Volatility	
Vapor Liquid (V/L) Ratio	Vapor lock
Distillation	Cool weather driveability, hot start and hot driveability, vapor lock, evaporative losses, crankcase deposits, combustion chamber and spark plug deposits
Vapor Pressure (VP)	Low temperature starting, evaporative losses, vapor lock
Copper Corrosivity	Fuel system corrosion
Stability	
Existent Gum	Induction system deposits, filter clogging
Oxidation Stability	Storage life
Sulfur Content	Exhaust emissions, engine deposits and engine wear
Metallic Additives (lead and others)	Catalyst & oxygen sensor deterioration (unleaded vehicles)
Temperature for Phase Separation	Water tolerance of blended fuels

unleaded fuel because lead can foul catalysts. The Clean Air Act Amendments of 1990 prohibits the sale of leaded gasoline after December 31, 1995 except for certain aviation and racing applications . Lastly, a temperature for phase separation specification is used to determine the water tolerance of blended fuels (ethanol and methanol blends).

Much like the settings that are created to control the automobile, such as spark plug gap, timing, and idle speed, the control standards for gasoline determine how well a gasoline performs. The major difference however, is that the specifications for an automobile engine are designed to make that engine perform as it should. In the case of gasoline, the specifications or standards are a control of physical properties, compromises to enable gasoline to perform well across a broad range of automobiles and climates.

These general standards satisfy the widest range of vehicles and operating circumstances possible. However, even fuels meeting specification can contribute to driveability problems in some vehicles under some operating conditions. When these isolated cases occur they can, of course, present difficulty for the technician in diagnosing the problem and identifying the proper course of action.

Gasoline Component Specifications

Generally, there are no ASTM specifications or standards for the individual components contained in gasoline. A few notable exceptions are some of the oxygenates such as ethanol and methyl tertiary butyl ether (MTBE). Ethanol is manufactured outside of the refinery, and is added to the gasoline by the fuel manufacturer. Due to the widespread use and increasing market share of gasoline/ethanol blends, ASTM in 1988, adopted a standard specification for fuel grade ethanol (ASTM D 4806). This standard sets guidelines for purity and other important properties for ethanol that is to be blended into gasoline. Adherence to this standard ensures that high quality ethanol is used in the manufacture of such blends. Major ethanol producers often establish additional guidelines which may exceed ASTM requirements. In addition, the Renewable Fuels Association (RFA), the trade group for the U.S. fuel ethanol industry, has established specifications and quality standards for ethanol manufactured by its member companies (RFA Recommended Practice 911201).

MTBE is also sometimes added outside of the refinery process. Accordingly, ASTM has also been working on a standard specification for MTBE used in such blending. As with ethanol, this standard will set guidelines for purity and other important properties. It is anticipated that ASTM will finalize and publish this new standard in the near future.

It is likely that as other oxygenates achieve the widespread use enjoyed by ethanol and MTBE that specifications will be established for them as well.

Gasoline Additives

Although not specifically included in ASTM standards, a variety of specially formulated additives are added to gasoline to enhance fuel quality and performance, and to maintain fuel standards during distribution.

These gasoline additives are mixed in very small quantities. As an example, 100 pounds of deposit control additive may treat as much as 20,000 gallons of gasoline. Many of these additives are also available in diluted form as over-the-counter products for consumer addition. Table 1-5 lists the most common additives and why they are used.

Benefits to the consumer are numerous and may include improved performance, increased engine life, lower deposits, driveability improvements, and better fuel economy.

These additives are extremely expensive and you should not have to worry about them being added in excess. At recommended treat rates, these additives may enhance fuel quality.

Table 1-5
Gasoline Additives

Additive	Purpose
Detergents/deposit control additives*	Eliminate or remove fuel system deposits
Anti-icers	Prevent fuel-line freeze up
Fluidizer oils	Used with deposit control additives to control intake valve deposits
Corrosion inhibitors	To minimize fuel system corrosion
Anti-oxidants	To minimize gum formation of stored gasoline
Metal deactivators	To minimize the effect of metal-based components that may occur in gasoline
Lead replacement additives	To minimize exhaust valve seat recession

* Deposit control additives can also control/reduce intake valve deposits

A good example of fuel quality improvement with such additives is the increase in usage of detergents and deposit control additives and the positive impact it has had in minimizing the incidence of port fuel injector fouling. Other gasoline additives include anti-icers to provide protection against fuel line freeze up; fluidizer oils used in conjunction with deposit control additives to control intake valve deposits; corrosion inhibitors to minimize fuel system corrosion; anti-oxidants to minimize gum formation while gasoline is in storage; and in some cases metal deactivators are utilized to minimize the effect of metal based components sometimes present in gasoline.

In the mid 1980s, refiners began to reduce the lead content of leaded gasoline to comply with EPA regulations. As of January 1, 1996 the EPA no longer permits the sale of leaded gasoline anywhere in the U.S. (except certain racing and aviation applications). In response to reduced lead levels and now the unavailability of leaded gasoline, some additive manufacturers have developed lead replacement additives.

Pre-1971 vehicles, as well as certain farm machinery and marine equipment, do not have hardened valve seats. In these vehicles, metal-to-metal contact between the exhaust valve and exhaust valve seat is prevented by a build up of lead oxides from the combustion of leaded gasoline. Unleaded gasolines provide no such protection against exhaust valve seat recession (EVSR). While pre-1971 vehicles in normal street use are not at great risk, numerous tests have shown that engines without hardened valve seats are at risk of EVSR if the equipment is operated at high RPMs or under heavy loads. Consumers operating such vehicles or equipment under these more severe conditions may wish to check with the vehicle/equipment manufacturer for recommendations regarding lead substitutes. Though some refiners serving rural areas may use such an additive in their gasoline, these products are typically sold over the counter in 8 to 12 oz. bottles. These additives should not be added in amounts exceeding the recommended treat rates, as to do so could increase engine deposits.

Chapter 2 Changes in Gasoline Driven by Environmental Concerns

Background

Over the past three decades, efforts to control the environmental impact of automobiles and the fuels that power them have proven increasingly complex. Early efforts focused on controlling the emissions of the automobile, first with simple devices such as positive crankcase ventilation (PCV) valves. These changes were followed by catalytic converters, exhaust gas recirculation (EGR) systems, evaporative emissions canisters, and an increasingly complex array of computer controls, modifications to air/fuel management systems, and various sensors to provide input to the vehicle computer. The carburetor, replaced by port fuel injection, has become a dinosaur in less than a decade. Many vehicle manufacturers have also begun utilizing engines with three or four valves per cylinder in an effort to improve fuel economy and reduce emissions while maintaining performance. While these modifications have resulted in an increasingly complex vehicle, they have achieved significant reductions in vehicle emissions. Compared to pre-control era vehicles, exhaust emissions of carbon monoxide (CO) and hydrocarbons (HC) have been reduced by 96% while nitrogen oxide (NO_x) emissions have been reduced by 76%.

Most of the vehicle emission reductions to date have been achieved through vehicle technology. However, with much of this technology already implemented, attention has been increasingly directed to developing cleaner burning fuels. These efforts initially focused on removing or adding various components and reducing fuel volatility. However, as with the automobile, these efforts have grown increasingly complex and will now include more complex compositional changes to gasoline.

Compositional change to gasoline is not a new concept. Over the years, gasoline composition has changed as a result of new refining technology, changes in crude oil feedstock, and variations in the demand for finished products. Recent changes, however, have been driven by environmental considerations and this trend will continue. This will add to the difficulty of balancing environmental requirements with fuel performance standards.

The first environmentally driven change was the introduction of unleaded gasoline for use with catalytic converter-equipped vehicles.

Next came the reduction in lead content of the leaded grade. Lead content was reduced dramatically in the mid 1980s and by January 1, 1986 was limited to 0.1 gram per gallon. As of January 1, 1996 the addition of lead to automotive gasoline is no longer permitted.

The first gram of lead added to a gallon of gasoline raises the (R+M)/2 (pump octane) about six octane numbers. The need to manufacture more unleaded gasoline and to phase out the use of lead initially strained some refiners octane capabilities.

The refiners and petroleum industry responded to this need for octane through a variety of actions. These actions included utilizing more complicated manufacturing processes and also the addition of oxygenates (alcohols and ethers) to gasoline.

The use of more complex refining processes during the 1980s resulted in increased levels of aromatics, olefins/diolefins, and "light end components" in gasoline.

Aromatics include products such as benzene, a known cancer causing agent; toluene, a known toxin; and xylene which is a major contributor to smog formation. In addition, these products may contribute to elastomer deterioration in some vehicle fuel systems. The average aromatic content of gasoline increased from around 20% in the 1970s to approximately 32% in 1990 with many gasolines exceeding a 40% aromatic content.

Olefins and diolefins present environmental concerns due to their contribution to smog formation. These components may also contribute to the formation of gums and lacquers in vehicle engines. They are also thought to be one of the factors contributing to fuel injector and intake system deposits.

The resulting increase in production of light end components, such as butane, increased their use in gasoline to enable utilization of all refinery streams. The butane content of gasoline increased significantly by the mid-1980s. This had a dramatic impact on fuel volatility.

The end result of these efforts to maintain octane quality was a gasoline that was more volatile. This resulted not only in hot driveability problems but also in increased evaporative emissions. Evaporative emissions of hydrocarbons contribute to ground level ozone formation, another concern to EPA. Between 1980 and 1985, the average vapor pressure of summer grade gasoline increased from 9.8 psi to 10.4 psi. This vapor pressure increase led EPA to implement rules to reduce the volatility of summer grade gasoline. This was done in two phases. The first phase which required vapor pressures ranging from 9.0 psi to 10.5 psi was implemented in the summer of 1989.

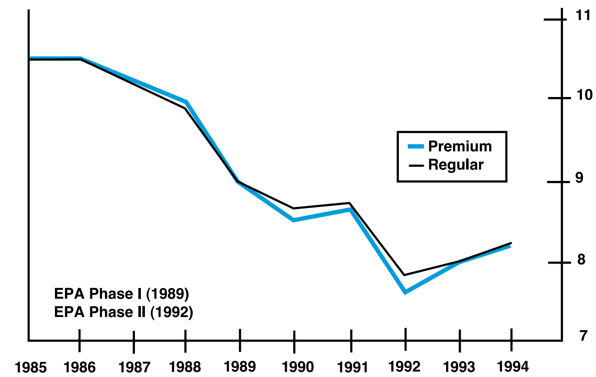
In 1992, EPA implemented Phase II of their volatility control levels which requires that gasoline sold (at retail) between June 1st and September 15th have a vapor pressure of no more than 9.0 psi. Southern ozone non-attainment areas are required to sell gasoline with a vapor pressure of no greater than 7.8 psi during this control period. As with Phase I of their program, EPA will permit gasoline/ethanol blends (containing 9% to 10% ethanol) to be up to 1.0 psi above the vapor pressure requirements for gasoline.

In addition to further reducing evaporative emissions, the Phase II volatility controls have nearly eliminated fuel related hot driveability problems in all but the most sensitive of vehicles.

Figure 2-1 depicts the summertime fuel volatility trends for 1985 to 1994 and graphically displays the significant decreases in volatility achieved by the EPA Volatility Controls

Also during the 1980s, some areas began to experiment with oxygenated fuel programs as a way to reduce tailpipe

Figure 2-1 Vapor Pressure of Summer Gasoline



Source: AAMA U.S. Gasoline Survey

emissions of CO. In January 1988, certain areas of Colorado became the first localities to mandate the use of oxygenated fuels during certain winter months. Oxygenated gasolines contain oxygen-bearing compounds (alcohols or ethers).

By 1991, several other western cities had followed Colorado's lead and there were eight areas of the nation utilizing such programs during winter months when CO levels are traditionally highest.

The requirements for these early programs were met almost exclusively through the use of ethanol and methyl tertiary butyl ether (MTBE). Since these compounds add oxygen to the air/fuel mixture, they chemically enlean the air/fuel charge resulting in more complete combustion and lower carbon monoxide emissions.

These programs were quite successful and led to Congress exploring similar provisions for all CO non-attainment areas when they prepared the 1990 Clean Air Act Amendments. This brings us to the most recent round of environmentally driven changes to gasoline

1990 Clean Air Act Amendments

In November 1990, then President Bush signed the Clean Air Act Amendments of 1990 (CAAA90) into law. These amendments included provisions that required the use of oxygenated fuels in nearly all CO non-attainment areas effective in 1992 and required the introduction of reformulated gasolines in certain ozone non-attainment areas starting in 1995. The amendments also included a requirement that all gasolines contain a detergent/deposit control additive that keeps carburetors, fuel injectors, and intake valves clean. Other provisions in the amendments included the elimination of the addition of lead to any automotive gasoline.

Gasolines that are not regulated under the reformulated gasoline or oxygenated gasoline programs are subject to what is called the "anti-dumping rules" of the amendments. These requirements regulate conventional gasoline in a manner to ensure that its composition does not lead to increased emissions, or in other words, the fuel cannot become any "dirtier" than it was in 1990. The major gasoline related provisions of the 1990 Clean Air Act Amendments are recapped in Table 2-1.

See Appendix B for areas of the nation that are currently required to use oxygenated fuels and reformulated gasoline.

The above mentioned programs have led to three distinct families of gasoline, conventional gasoline, oxygenated gasoline, and reformulated gasoline. While these gasolines are similar, there are some minor differences and this has led to some confusion about the composition and characteristics of these fuels. A brief description of each gasoline category follows.

Table 2-1: Gasoline Related Programs of the 1990 Clean Air Act Amendments

- Oxygenated fuels required in CO non-attainment areas beginning in 1992 (winter months)
- Reformulated gasoline required in certain ozone non-attainment areas beginning in 1995 (year round)
- Detergents required in all gasoline beginning in 1995 (year round)
- No lead allowed in gasoline beginning 1995 in reformulated gasoline areas and 1996 in all other areas.
- Anti-dumping provisions regulate conventional gasoline to present emissions levels beginning in 1995.

Conventional Gasoline: Conventional gasoline represents all gasoline sold in non-control areas or in other words, all gasoline that is not regulated under the oxygenated or reformulated gasoline programs. Conventional gasoline is subject to the previously mentioned anti-dumping rule. The rule requires that each refiner cannot produce gasoline that, on average, would increase emissions of volatile organic compounds (VOC), oxides of nitrogen (NOx), carbon monoxide (CO), and toxic air pollutants (TAP) when compared to the gasoline they were producing in 1990 (See Table 2-2). Toxic air pollutants are defined as benzene, 1,3 butadiene, polycyclic organic matter, acetaldehyde, and formaldehyde. These regulations were implemented to eliminate any increases in emissions resulting from the composition of conventional gasoline.

Table 2-2 Clean Air Act - Conventional Gasoline Anti-Dumping Requirements

Compared to their 1990 averages, each refiner's gasoline cannot result in higher emissions of the following:

Volatile organic componds	(VOC)
Oxides of Nitrogen	(NO_x)
Carbon monoxide	(CO)
Toxic air pollutants	(TAP)
Benzene	
1,3 Butadiene	
Polycylic organic matter	
Acetaldehyde	
Formaldehyde	

Conventional gasoline may, and often does, contain oxygenates such as ethanol and methyl tertiary butyl ether. Ethanol content is limited to a maximum of 10% by volume and MTBE is limited to a maximum of 15% by volume, Conventional gasoline continues to be subject to ASTM performance standards as covered in Chapter 1.

Oxygenated Gasoline Programs: The Clean Air Act Amendments require that CO non-attainment areas sell only oxygenated gasoline during certain winter months, usually for a four month period. The applicable months vary by area depending upon the historical pattern of CO violations. The most common time frame for these programs is November through February. These are wintertime only programs because that is when nearly all violations of the federal CO standards occur.

Each state has some flexibility in controlling its specific program so details and procedures may vary slightly from one state to the next. Basically, each state requires that gasoline sold during the designated control period contain an average of 2.7 weight percent oxygen (California's program requires only 2.0 weight percent oxygen). This is typically achieved by the addition of 7.8 volume percent ethanol (ethanol can be added at up to 10 volume percent) or 15 volume percent MTBE. Other permitted oxygenates and the levels required to achieve the standard would include tertiary amyl methyl ether (TAME) at 17.2 volume percent and ethyl tertiary butyl ether (ETBE) also at 17.2 volume percent. Though some other types of oxygenates are permitted, they have not been used at any significant levels. The principal underlying the oxygenated fuels program is very simple. The chemically bound oxygen in the gasoline enleans the air fuel ratio. This results in more complete combustion and hence lower CO emissions. This reduction varies depending upon oxygen level, vehicle technology, and state of tune. The reduction in CO typically ranges from 10% to 30% with older vehicles experiencing the greatest reduction. Modest reductions of tailpipe emissions of hydrocarbons (HC) are also experienced in many vehicles.

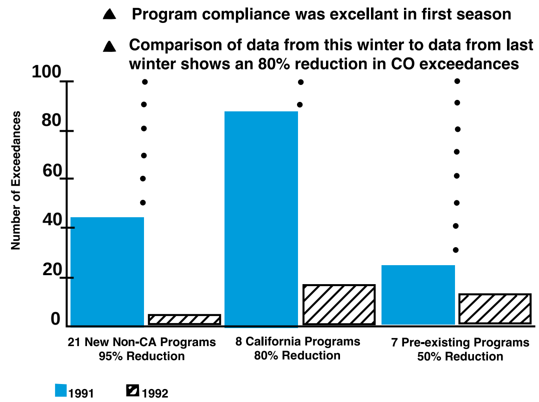
The winter of 1992/1993 was the first year that the oxygenated fuel programs were implemented on a nationwide basis. The program was extremely successful with impressive reductions in CO emissions.

The seven pre-existing programs in the western states continued to enjoy ongoing reductions with the number of CO exceedances dropping by 50% compared to the previous year. The eight new California program areas experienced an 80% reduction in violations. The twenty-one new non-California program areas experienced a 95% drop in the number of CO exceedances. See Figure 2-2. These results represent the greatest year to year reduction in CO exceedances since records have been kept and clearly demonstrate the positive results of the oxygenated gasoline program

Oxygenated gasoline must meet not only the minimum wintertime oxygen requirement but it is also subject to the anti-dumping provisions for conventional gasoline. Oxygenated gasoline is also subject to ASTM performance standards.

Put another way, oxygenated gasoline is simply conventional gasoline that is required to contain a minimum level of oxygen. Now in place for over four years, the accomplishments of these programs are well established.

Figure 2-2
OXYGENATED FUEL PROGRAMS
FIRST YEAR RESULTS



Note: California has 2.0% oxygen by weight progtrams.
Source U.S. EPA

Source U.S. EPA

NOTE: In some areas a CO non-attainment area may also be an ozone non-attainment area participating in the reformulated gasoline program. In these cases the minimum wintertime oxygen standard applies during applicable months while reformulated gasoline requirements must be met on a year round basis.

Reformulated Gasoline: The Clean Air Act Amendments required the nine worst ozone non-attainment areas (classified as Extreme or Severe) to implement reformulated gasoline (RFG) programs. These areas included the following metropolitan areas; Baltimore, Chicago, Hartford, Houston, Los Angeles, Milwaukee, New York City, Philadelphia, and San Diego.

Other ozone non-attainment areas (classified as serious, moderate, or marginal) may "opt-in" to the RFG program upon request of that state's governor to the EPA. Several governors have made such requests resulting in several other areas being subject to the reformulated gasoline requirements.

In the presence of heat and sunlight, hydrocarbon emissions (both tailpipe and evaporative) react with NO_x to form ground level ozone. The requirements for reformulated gasoline are designed to reduce this reaction.

NOTE: A distinction should be made at this point with regard to reformulated gasoline as an ozone control strategy. Technicians are currently dealing with CFC (chlorofluorocarbons) reclamation programs to reduce ozone depletion in the upper atmosphere, where it provides protection against harmful ultraviolet rays. However, at ground level, ozone is a respiratory irritant. It is particularly harmful to young children, the elderly, and those with respiratory conditions. Ozone is the principal ingredient in smog. Reformulated gasoline programs are directed toward reducing ground-level (lower atmosphere) ozone.

In the late 1980s, ARCO introduced EC-1, the nation's first gasoline marketed as a reformulated fuel. Other petroleum companies soon introduced fuels that they marketed as a reformulated gasoline. However, the Clean Air Act Amendments set specific guidelines for what is now termed as reformulated gasoline or RFG. The EPA has further defined these guidelines through a series of rulemakings and information documents.

There are actually two phases to the RFG program. Phase I of the program applies for calendar years 1995 through 1999. Phase II is scheduled to begin on January 1, 2000.

Phase I of the program requires a 15% reduction in both ozone forming volatile organic compounds (VOC) emissions and toxic emissions with no net increase in oxides of nitrogen (NO_x). Phase II of the program requires a 25% reduction in VOCs and a 20% reduction in toxic emissions and a 5.5% reduction in NO_x.

Phase I of the program is divided into two parts defined best by the mechanism of compliance. To ease the petroleum industry's compliance burden (due to the short lead time between the final regulations and initial compliance dates) the EPA developed what has come to be called the "Simple Model" for use in calendar years 1995 through 1997.

Refiners are deemed to be in compliance if their RFG meets the requirements of the simple model. The limitations of the simple model include a maximum of 1.0 volume % benzene, a 2.0 weight % minimum oxygen content, and no net increase in NO_x. Sulfur, olefins, and the 90% distillation point are capped at the refiners average values for their 1990 gasoline production. The aforementioned standards apply on a year round basis. In addition the summer grade of gasoline (defined as June 1st to September 15th at the retail level) must meet reduced volatility standards. This is defined as a vapor pressure of no more than 7.2 psi for the southern ozone non-attainment areas (Class B areas or lower) or 8.1 psi for northern ozone non-attainment areas (Class C areas). The simple model RFG requirements are listed in Table 2-3.

Table 2-3
Reformulated Gasoline - EPA Simple Model

• Benzene	1.0 volume % maximum
• Volatility	7.2 psi vapor pressure in Class B areas 8.1 psi vapor pressure in Class C areas
• Sulfur, olefins, 90% point	Capped at the average values of the refiner's 1990 gasoline
• NO_x	No net increase
• Oxygen	2.0 weight % minimum

NOTE: All standards apply year round except volatility. The volatility standard applies from June 1st to September 15th of each year (at the retail level)

EPA has prepared a "complex model" that must be used beginning in 1998. Refiners may also use the complex model sooner on a voluntary basis in which case it would replace use of the simple model for a given refiner.

The complex model is a series of very complicated equations developed into a computer model. Results from various test programs, measuring the effect of various fuel changes on automobile emissions, were used to construct these equations. The model data base includes several test programs that have been peer reviewed and deemed appropriate for inclusion. These tests looked at the emissions effects of such characteristics as oxygen content (by oxygenate type) aromatic level, olefin content, vapor pressure, and distillation characteristics.

The model developed from these tests enable the prediction of emissions reductions (or increases) that result from various changes to the fuel. A refiner can utilize the complex model to achieve the RFG requirements. This enables a refiner to meet the environmental standards and performance standards in a manner most suitable to their refinery capabilities.

Though the term reformulated gasoline has been perceived as distinguishing a new product, in reality there is very little about RFG that is different. There is nothing present is RFG that cannot be found in conventional gasoline. The levels of certain ingredients are simply altered to reduce emissions. Nor are the performance standards any different except for slightly lower volatility for the summer grade. In fact when RFG was introduced in 1995, it was already a proven product having been sold in California since 1992. California's RFG program, with more detailed restrictions and a faster implementation schedule, differs somewhat from the federal requirements.

It is estimated the use of reformulated gasoline will reduce vehicle emissions by over two billion pounds per year. This is equivalent to removing eight million automobiles from the road.

Reformulated gasoline, oxygenated fuel, and individual oxygenates are discussed in greater detail in Chapter 3.

Detergent Requirements: The 1990 Clean Air Act Amendments also required, beginning in 1995, that all gasolines be treated with detergents and deposit control additives to minimize deposits in carburetors, fuel injectors, and on intake valves. The EPA is also exploring the possibility of setting standards to control combustion chamber deposits. Fuel intake system deposits are an environmental issue because increased levels of deposits can increase exhaust emissions of HC or NO_x depending upon operating mode.

Other Information: While all gasolines must continue to meet vehicle performance standards, it is clear that current changes in gasoline are driven by environmental considerations.

As more conclusive data is developed it is likely that further changes will occur. Research in this area is ongoing with new data being accumulated by both government and industry. The three domestic auto manufacturers and fourteen large oil companies have formed a research consortium called the Air Quality Improvement Research Program (AQIRP). The objective of this program "is to conduct a research and testing program to develop data on potential improvements in vehicle emissions and air quality — primarily ozone — from reformulated gasoline, various other alternative fuels, and developments in automotive technology."

Phase I of this multi-million dollar program examined emissions from current and older vehicles using different variations of reformulated gasolines with widely varying aromatic content, olefin content, oxygenate content and type, sulfur content, vapor pressure and 90% distillation points. This phase of the program also examined emissions from flexible fueled vehicles operating on a mixture of 85% methanol/15% gasoline. Phase I of the program was designed to help identify fuel characteristics that need further study in future phases of the program.

This program is now well into Phase II which will further define various fuel characteristics and their impact on vehicle emissions. Data developed from the AQIRP program was one of the information sets used in developing the equations for EPA's complex model. More importantly, research work such as this helps scientists and engineers focus on the fuel changes with the greatest prospect for environmental improvements.

Chapter 3 Reformulated Gasoline, Oxygenates, and Oxygenated Fuels

Background

In many cases the widespread introduction of oxygenated fuels and reformulated gasoline were accompanied by unnecessary confusion and concern among consumers. This was due, in large part, to inaccurate or incomplete media reports. In addition, some service technicians were not provided adequate information on the fuels so that they could discuss pertinent issues with their customers, the auto owners.

This chapter will cover information that addresses the most often misunderstood performance issues pertaining to reformulated gasoline, oxygenated fuels, and the fuel oxygenates they both contain.

Reformulated Gasoline

First implemented in 1995 (1992 in California), the reformulated gasoline (RFG) program is one of the latest in a series of measures taken to provide cleaner burning automotive fuels. RFG is often confused with oxygenated gasoline. While both contain oxygenates, such as ethanol and MTBE, they are not exactly the same. Oxygenated fuels are simply conventional gasolines with an oxygenate added. Oxygenated fuels are sold during winter months to reduce CO emissions.

Reformulated gasolines also contain oxygenates but, as described in Chapter 2, undergo other compositional and property alterations to reduce ozone forming emissions. RFG is a year round program with slightly different versions of the fuel for summer and winter. All reformulated gasoline is oxygenated but not all oxygenated fuels are RFG. It should also be noted that conventional gasoline often contains oxygenates to boost octane.

Contrary to inaccurate media reports, RFG differs very little from conventional gasoline. The various properties are within the range of parameters for conventional gasoline. The primary differences between RFG and conventional gasoline are as follows:

- Benzene is limited to 1% in RFG.
- Volatility is reduced in summer grades of RFG.
- Each and every gallon of RFG must contain an oxygenate.
- As refiners switch to the complex model in 1998, other differences may include reduced levels of sulfur, aromatics, and olefins as well as reductions in the 90% evaporation point.

Each of the above four categories is discussed in more detail below:

Benzene Reduction: RFG can contain no more than 1% benzene. Benzene is relatively high in octane but is known to cause cancer in humans. The octane provided by benzene is replaced by oxygenates and hydrocarbons with appropriate boiling temperatures. The removal of benzene is therefore not a performance issue, simply a positive health benefit.

Volatility: Winter grade RFG will typically be of the same vapor pressure as conventional gasolines traditionally sold in a given area. The summer grade, however is of lower vapor pressure than conventional gasoline. RFG must meet a summer vapor pressure standard of 8.1 psi in northern RFG areas and 7.2 psi in southern RFG areas whereas conventional gasoline is typically 9.0 psi (or 7.8 psi in southern ozone non-attainment areas). It is important to note that the conventional gasolines were only recently (1992) lowered to these vapor pressure levels.

Vapor pressure is required to be lower to reduce evaporative emissions which can react in sunlight to form ozone. However such reductions also reduce the amount of vaporization during cold start and warm up. Any problems resulting from reduced vapor pressure would be limited to abnormally cold days and primarily to older carbureted vehicles. For instance, summer grade RFG is required at retail by June 1st but it is required at terminals by May 1st. This means terminals start receiving, and may start shipping, reduced vapor pressure summer grade in early May or even late April. Temperatures in northern climates in May can easily drop to 50˚F or below. At 50˚F, 10.0 psi vapor pressure would provide better cold start and warm up performance than an 8.1 psi vapor pressure gasoline. This does not mean that cars will fail to start, simply that carbureted vehicles may require slightly longer cranking times and warm up performance could be affected. However this would be limited to those late spring and early summer days where temperatures fall below 60˚F.

Oxygen Content: All RFG must contain an oxygenate. The average per gallon oxygen content required is 2.0 weight percent.

The effect oxygenates have on RFG are the same as when oxygenates are added to conventional gasoline. These effects are discussed more thoroughly under the section on oxygenated fuels and oxygenates. (See pages 14-18)

The most often discussed effect is the impact on fuel economy which averages about 2.0% lower on modern vehicles in a proper state of tune. This is also discussed in greater detail on the following pages.

Actual Variation: Again it is important to note that there is really very little difference between the composition and characteristics of RFG when compared to conventional gasoline. The content and specification parameters for conventional gasoline and RFG are compared in Table 3-1. As can be seen from the table, the characteristics of RFG fall within the range of characteristics typical of coventional gasoline.

Future Changes: As refiners move to production of the "Complex Model" RFG, additional changes are likely to be made. These will likely include reductions in sulfur and olefins content. Sulfur and olefins are both bad actors in gasoline. Sulfur reduces the effectiveness of the catalytic convertor and at high levels can contribute to premature engine wear. Excessive sulfur can also result in a "rotten egg" odor from the catalytic converter. Olefins have been shown to contribute to some forms of fuel system deposits. So reductions of these ingredients will improve fuel quality.

In some cases aromatics may be reduced, especially heavy aromatics, and heavy hydrocarbons that could, by their removal, reduce the 90% distillation temperature. Some aromatics are high octane. However any lost octane will be replaced by oxygenates and other hydrocarbons since the finished fuel will still be required to meet octane quality guidelines.

Table 3-1 Comparison Conventional Gasoline to RFG (Typical Properties)

Property	Conventional Gasoline Range	Phase I RFG
Reid Vapor Pressure (psi)	6.9 - 15.1	7.2 - 15.0
T50 (˚F)	141 - 251	202
T90 (˚F)	286 - 364	316
Aromatic (vol %)	6.1 - 52.2	23.4
Olefins (vol %)	0.4 - 29.9	8.2
Benzene (vol %)	0.1 - 5.18	1.0
Sulfur (ppm)	10 - 1170	302
MTBE (vol %)	0 - 15.0	11.0
Ethanol (vol %)	0 - 10.4	5.7
Oxygen content (wt %)	0 - 3.6	2.0
Octane ([R+M]/2)	87 - 93	87 - 93

Source U.S. EPA

Some tests have shown that removal of heavy aromatics and hydrocarbons will reduce fuel induction system and combustion chamber deposits. This should result in RFG being cleaner, not only for the air but for the fuel system and vehicle engine.

While positive for the environment, one minor drawback is that reductions in heavier gasoline components will slightly reduce the energy content of the gasoline. This could contribute to a fuel economy reduction beyond the average 2% reduction expected from oxygenate addition. It is not yet possible to predict the fuel economy effect of such changes but they would likely be very small, in the 1-2% range.

Oxygenates

The term oxygenated fuels can apply to various types of fuels. In most cases it is used to refer to the oxygenated fuel programs that require the use of oxygenated fuels during winter months in CO non-attainment areas. However reformulated gasoline also contains oxygenates and conventional gasoline sometimes contains oxygenates to improve octane quality.

An oxygenated gasoline is oxygenated by the addition of an alcohol or ether. The most commonly used alcohol is ethanol and the most commonly used ether is methyl tertiary butyl ether (MTBE). Other oxygenates such as ethyl tertiary butyl ether (ETBE) and tertiary amyl methyl ether (TAME) have recently started being used, primarily in RFG.

Before discussing oxygenated fuels, a review of information on the commonly used oxygenates is in order.

Ethanol: Ethanol is widely used and available in most areas of the U.S. Ethanol has seen continued growth as a gasoline component since the late 1970s when it was used as a product extender due to gasoline shortages. At that time gasolines containing ethanol were called gasohol. Later, when gasoline was more plentiful, ethanol began to see widespread use as an octane enhancer and the name gasohol was dropped in favor of names reflecting the increased octane (e.g. unleaded plus, super unleaded plus).

As with the other oxygenates, the use of ethanol as a gasoline component will improve combustion and thereby reduce CO emissions. Some studies have indicated that, used in a correctly formulated fuel, the use of ethanol can also reduce emissions which contribute to ozone formation.

More recently, ethanol supporters have focused attention on ethanol's ability to provide octane while replacing other environmentally harmful components in gasoline. Other studies suggest that using ethanol can also slow global warming when compared to gasoline. Ethanol also reduces imports by replacing imported gasoline and crude oil.

Ethanol is already contained in over ten percent of all gasoline sold in the United States. It is, or has been, used or marketed by such companies as Exxon, Sunoco, Marathon, Texaco, Amoco, Mobil, ARCO, Super-America, Chevron, Union, BP, Shell, and Phillips as well as numerous independent marketers. Trillions of miles have been driven on ethanol-blended gasolines.

In the early years of use, ethanol was added to gasoline in the transport truck at a terminal located away from the gasoline terminal. For a number of years now, the ethanol blending process has been much more sophisticated. Ethanol is located at the gasoline terminal or refinery loading rack and is metered into the gasoline to achieve an exact blend.

Blends exceeding 10 volume percent ethanol are not permitted by law, nor are they likely to occur, because ethanol costs much more than gasoline, making higher-level blends uneconomical.

Ethanol has an affinity for water. It picks up moisture throughout the fuel system and prevents fuel line freeze up. In the early gasohol era, this sensitivity to water led to problems because service stations often had water in the bottom of their underground tanks. Today, the petroleum industry is well aware of these considerations and companies using ethanol have implemented procedures to eliminate moisture in underground storage tanks. In fact, once tanks are properly prepared, ethanol helps eliminate the build up of water in the bottom of storage tanks.

The addition of 10 volume percent ethanol will typically contribute 2.5 or more octane numbers to the finished blend. The addition of ethanol increases vapor pressure by up to 1.0 psi although refiners may make other alterations to limit vapor pressure to comply with federal regulations. Ethanol is approximately 35% oxygen so a 10 volume percent blend would contain approximately 3.5 weight percent oxygen.

Ethanol is often confused with methanol. These two alcohols have distinctly different characteristics. Ethanol provides better water tolerance and better fuel system compatibility and contains less oxygen than methanol. Ethanol results in only a slight increase in fuel volatility, often less than would be found between various batches of gasoline within a market area. Unlike ethanol, methanol is very toxic.

In the United States, ethanol is produced by the fermentation of agricultural products, primarily corn. It is the same alcohol used in beverage alcohol but meeting fuel grade standards. The ethanol used in gasoline is denatured to make it unfit for drinking.

MTBE (Methyl Tertiary Butyl Ether): Methyl tertiary butyl ether has experienced exceptional growth in the past fifteen years. As with ethanol it was originally used as an octane enhancer. It is used by nearly every major oil company in at least some of their gasoline. MTBE is present, at various levels, in over 25% of all gasoline sold in the U.S. As an octane enhancer, MTBE is usually blended at levels of 6 to 8 volume percent. In oxygenated fuels, MTBE is blended at 15 volume percent and in RFG at 11 volume percent. These higher levels are necessary to meet the minimum oxygen content standard.

At higher levels MTBE will contribute 2.5 to 3.0 octane numbers to the finished gasoline blend. MTBE is not as sensitive to water as are the alcohols and does not increase the volatility of most gasolines.

MTBE is manufactured by the chemical reaction of methanol and isobutylene. The conversion of methanol to MTBE eliminates the unfavorable characteristics associated with methanol. The finished ether does not contain methanol.

MTBE and other ethers have a very distinct odor. This has led to some complaints by motorists who find the odor unpleasant and in some cases claim the smell has made them nauseous or caused eye irritation or rashes. These reports have been sensationalized by the media making study of these complaints difficult. Though studies continue, the work thus far indicates that MTBE provides both environmental and health benefits when compared to the products in gasoline that it replaces.

TAME (Tertiary Amyl Methyl Ether): Recently, some refiners have started using TAME to enhance octane and to provide oxygen for compliance primarily with reformulated gasoline requirements. Although there is less experience with TAME compared to the other oxygenates, its performance characteristics are generally considered to be similar to those of MTBE. TAME is permitted in gasoline at levels up to approximately 17.2 volume percent, although it is usually used at much lower levels. At maximum permitted levels, TAME can contribute up to 3.0 octane numbers to the finished blend which would then contain an oxygen level of 2.7 weight percent.

TAME will actually lower the vapor pressure of the gasoline to which it is added. Currently TAME is present in only a small percentage of gasoline sold, but its use is expected to grow as new production facilities come on line.

TAME is manufactured by the chemical reaction of methanol and isoamylene. As with MTBE, this conversion eliminates the unfavorable characteristics of the methanol.

ETBE (Ethyl Tertiary Butyl Ether): ETBE has only recently begun seeing any level of commercial use. Various test programs have indicated that the performance characteristics of ETBE are similar to MTBE. The maximum permitted level of ETBE is 17.2 volume percent. At this level ETBE contributes up to 3 octane numbers to the finished blend which would contain 2.7 weight percent oxygen. ETBE will lower the vapor pressure of the gasoline to which it is added. The low vapor pressure characteristics of ETBE makes it an attractive blend component for reformulated gasoline. ETBE is manufactured by reacting ethanol and isobutylene similar to the other ether processes.

Benefits: Clearly the primary benefit of oxygenates is their ability to contribute oxygen and octane to the gasoline to which they are added.

Figure 3-1 depicts the amount of oxygenate needed to achieve various oxygen levels in gasoline.

Reformulated gasoline must contain an average of 2.0 weight percent oxygen but may contain up to 3.5 weight percent oxygen. Oxygenated fuel programs require winter grades to have an average of 2.7 weight percent oxygen. All ethers are limited to a maximum of 2.7 weight percent oxygen. Ethanol blends can contain up to approximately 3.5 weight percent oxygen.

Figure 3-2 depicts the octane values of the four most commonly used oxygenates.

Other Oxygenates: Although the use of other oxygenates in gasoline is permitted, such use is not likely. The other alcohols and ethers permitted in gasoline are hampered by either high cost and/or unfavorable blending characteristics making their use in the near term very unlikely.

Oxygenated Fuels

Whether conventional gasoline, oxygenated gasoline, or reformulated gasoline, fuels containing oxygenates are perhaps the most misunderstood type of gasoline on the market. While it is accepted that oxygenated fuels improve octane quality, enhance combustion, and reduce exhaust emissions, many technicians still harbor doubts regarding

Figure 3-1

Volume Oxygenate Requirement for Regulatory Oxygen Levels

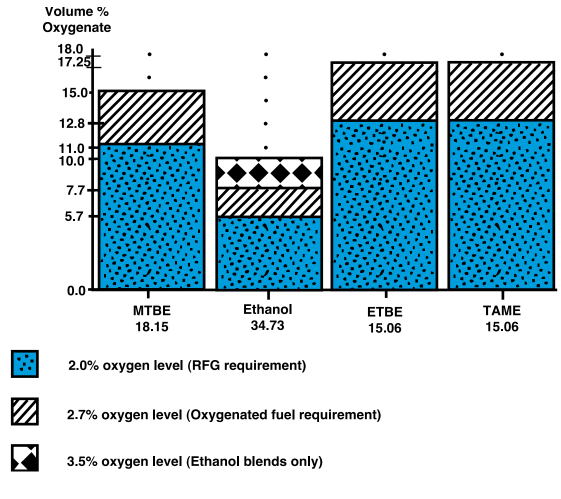
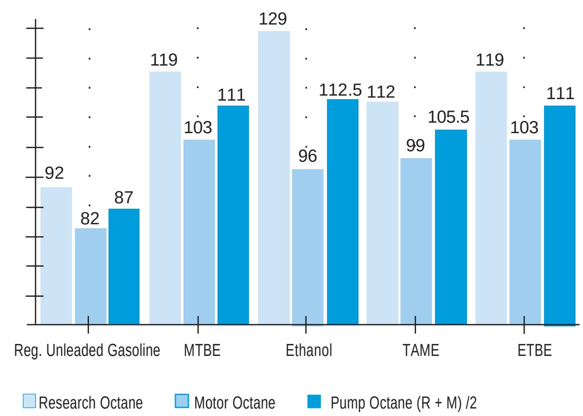


Figure 3-2
Octane Value of Common Oxygenates



Exact octane values will vary based on octane and composition of gasoline to which the oxygenate is added

volatility, energy content (fuel economy), materials compatibility, and fuel system deposits. Extensive testing has been conducted in each of these areas and the effects of oxygenates are well known.

Fuel Volatility: In the mid 1980s the vapor pressure of much of the gasoline was in excess of what automobile fuel systems were designed to handle during hot weather. This led to a rash of hot driveability/hot restart problems. It was during this time frame that oxygenates began to see widespread use and therefore these problems were often attributed to oxygenates such as ethanol. In reality, many fuels of that era, including hydrocarbon only fuels, were of unacceptably high vapor pressure.

Hot driveability/hot restart problems are primarily warm weather problems. Today, EPA regulates the vapor pressure of all gasoline during the summer months (June 1 to September 15 at retail) resulting in maximum permitted vapor pressures ranging from 7.2 psi to 10.0 psi depending on the type of gasoline and area in which it is sold. Therefore hot driveability and hot restart problems such as vapor lock and fuel foaming have been largely eliminated.

Materials Compatibility: Auto manufacturers have, for many years, used materials that are compatible with oxygenated fuels. However, with the widespread use of oxygenated fuels and reformulated gasoline, certain myths have resurfaced, so they warrant mention here. In earlier versions of this manual this topic was covered in greater detail, including photographs from various tests and applicable service bulletins. The information presented was segmented into two categories, metals and elastomers.

Most metal components in automobile fuel systems will corrode or rust in the presence of water, air or acidic compounds. The gasoline distribution system usually contains water, and additional moisture may collect in the automobile tank from condensation. Gasoline may also contain traces of sulfur and organic acids. Gasoline has always been recognized as potentially corrosive. Pipelines which distribute gasoline routinely require that corrosion inhibitors be contained in gasoline to protect their plain steel pipe. Therefore, corrosion inhibitors have been routinely added to gasoline for many years.

MTBE is slightly soluble in water and could increase the water-holding characteristics of gasoline by a very small amount. However, MTBE has not been shown to increase the corrosion level of gasoline.

Alcohols are more soluble in water than MTBE. The addition of ethanol will increase a gasoline's ability to hold water. Therefore, an ethanol enhanced gasoline may have a slightly higher moisture content than non-blended gasoline. Several tests have been reported on ethanol enhanced gasolines. Vehicle fuel tanks and fuel system components from autos operated for extended periods on these blends were removed, cut open, and examined. These tests have generally concluded that ethanol does not increase corrosion in normal, everyday operation.

Auto manufacturers have indicated they do not have major concerns about metal corrosion, provided that all fuels contain effective corrosion inhibitors at the proper treatment levels. Responsible ethanol producers recognize that not all commercial gasolines are adequately treated for blending, and have, for some time, included a corrosion inhibitor in their ethanol. Additionally, there are ASTM specifications to ensure that fuel grade ethanol is suitable for addition to gasoline. Many manufacturers utilize guidelines even more stringent than those established by ASTM. Due to these controls and the addition of corrosion inhibitors, you should not encounter ethanol-related corrosion problems.

Elastomer compatibility is more difficult to generalize. A number of gasoline ingredients can have an effect on elastomer swelling and deterioration. For instance, aromatics, such as benzene, toluene, and xylene, have been shown to have detrimental effects on some fuel system elastomers. Gasolines sold today have a higher level of aromatics than those sold in the 1970s.

The addition of alcohols or ethers to gasoline can also cause swelling in fuel system elastomers. Swelling can be severe with methanol, but relatively insignificant with other alcohols. Ten volume percent ethanol contributes less swelling than the amount of additional aromatics needed to obtain the same increase in octane number. The combination of ethanol or MTBE with high aromatic levels may cause greater swelling than either product by itself.

Automobile and parts manufacturers have been responsive to the changes occurring in today's gasoline. Materials problems are less likely to occur with newer vehicles because of the upgrading of fuel system materials that has occurred since the introduction of higher aromatic unleaded gasolines and the addition of alcohols and ethers. All major automobile manufacturers have indicated that their late model vehicles are equipped with fuel system components upgraded for use with these fuels.

While all auto manufacturers warrant the use of 10 percent ethanol blends and gasolines containing MTBE, their upgrading of fuel systems occurred at different times. In general, 1980 and later model years should not experience problems with 10 percent ethanol blends or gasoline containing MTBE. Fuel systems in 1975 to 1980 model years were upgraded, but not to the same extent as later models. Pre-1975 models may have fuel system components that are sensitive to high aromatic gasolines, alcohols and ethers. Specific documentation of the effect fuel components have on older fuel system parts is often lacking. Technicians who find themselves replacing parts on pre-1980 vehicles should specify that replacement parts be resistant to such fuel components. These products include Viton® (EGR valves, fuel inlet needle tips) and fluoro elastomers (fuel lines, evaporative control lines, etc.)

For more specific information on the various materials used in vehicle fuel systems, refer to Appendix A.

Other countries have been quick to identify fuel system materials which resist the changing composition of gasolines.

For several years the standard motor fuel in Brazil has been a blend of 22 volume percent ethanol in gasoline. Brazil also has over 5 million cars in operation on straight ethanol. Their ethanol program has been in operation for over ten years. The materials compatibility problems have been overcome. The benefits of their experience on a more severe application have assisted in identifying more suitable fuel system materials.

Numerous tests have indicated that materials compatibility on oxygenated fuels is no more of a concern than comparable hydrocarbon fuels and should not present any unique problems.

In the early 1980s, one area that presented problems in isolated cases was fuel filter plugging. Occasionally, in older model vehicles, deposits in fuel tanks and fuel lines were loosened by ethanol blends. When this occurs, the vehicle's fuel filter may become plugged. This is easily remedied by a filter change. It is not likely that such problems will be experienced on late model vehicles. Purolator Products addressed this issue several years ago with a 213 vehicle fleet test. This test program found no premature plugging and no failures related to gasoline-ethanol blends (see Figure 3-3 next page).

Fuel System Deposits: Numerous tests have shown that proper additive treatment effectively controls the deposit tendencies of gasolines including those containing oxygenates. The 1990 Clean Air Act Amendments require (as of

Figure 3-3 Excerpts from Purolator Products - Service Bulletin

Purolator products Service Bulletin

PUROLATOR GASOLINE FILTERS CAN BE USED WITH GASOHOL

> Purolator Products has been actively engaged in laboratory and field test analysis to determine the effects of gasohol on gasoline filters and their related components. The satisfactory results generated by accelerated laboratory compatibility testing has been confirmed by extensive field testing.
>
> The results to date are very encouraging. No filter related failures have been observed. Additionally, premature filter "plugging" during initial gasohol fill-ups has not been experienced. Filter "plugging" had been reported in other field studies utilizing gasohol.

January 1, 1995) that all gasolines contain a detergent/deposit control additive that controls deposits in carburetors, fuel injectors, and on intake valves. There are numerous considerations in effectively controlling fuel system deposits. These issues are covered in more detail in Chapter 4.

Oxygen Content and Enleanment: (Non-Feedback Systems) Oxygenated fuels may contain up to approximately 3.5 weight % oxygen depending on oxygenate type and level. This level of oxygen should not normally require any adjustments to the air/fuel ratio. However, you may occasionally encounter an auto which has the air/fuel ratio set lean. Since an increase in oxygen further enleans the fuel charge, these autos may display symptoms of enleanment (improper idle, engine dies). This can usually be easily corrected by minor adjustments to enrich the air/fuel mixture.

In those areas where vehicles are subject to Inspection & Maintenance (I/M) programs, care should be exercised to ensure that adjustment will not result in a failed emissions test.

(Feedback Systems) Newer vehicles are equipped with onboard computer control systems. These systems include oxygen sensors, installed in the exhaust manifold, to determine the oxygen content of the exhaust gases. Vehicles equipped with onboard computers will compensate for the oxygen content of the fuel when operating in the closed loop mode. The maximum level of oxygen permitted in gasoline is within the authority range of the sensor.

Phase Separation: Water in gasoline can have different effects on an engine, depending on whether it is in solution or a separate phase. Hydrocarbon gasoline cannot hold much water and the water quickly separates and, being heavier than gasoline, goes to the bottom of the tank.

A gallon of gasoline comprised solely of hydrocarbons can hold only 0.15 teaspoons of water (at 60˚F) before the water will separate. A blend containing 15 volume percent MTBE can hold about 0.45 teaspoons of water at 60˚F before the water separates. A gasoline blend containing 10 volume percent ethanol would require almost 4 teaspoons of water before phase separation would occur. Therefore in routine operations, oxygenates are more likely to suspend moisture and carry it out of the fuel system than non-oxygenated fuels.

When an ethanol blend begins to phase separate, not only will the water go to the bottom of the tank but it will pull a portion of the ethanol to the bottom as well.

With today's more stringent specifications and procedures to help keep moisture at a minimum throughout the distribution process, such occurrences are rare. Despite the rarity of phase separation, the technician should be able to identify this problem and respond accordingly.

To check for water contamination, draw a fuel sample from the bottom of the vehicle fuel tank or at the engine. Then pull a sample from the top of the fuel tank. If water is present, the samples should be noticeably different. If in doubt, you can add water soluble food coloring to the suspect sample. Water soluble food coloring will disperse through a water-laden sample (dye the water portion).

If water is present, all that is needed to correct the problem is to remove the water-contaminated fuel and refill the tank. It is best to completely refill the tank with an ethanol blend, since ethanol would absorb any trace amounts of water that remain. There is no need to replace any fuel system components.

NOTE: Any fuel or phase separation removed should be disposed of in accordance with any federal, state, or local regulations.

Fuel Economy: There is a great deal of misunderstanding about the fuel economy (miles per gallon) of various gasolines, especially those containing oxygenates.

There are a number of variables that confound accurate fuel economy measurements in anything short of a controlled test or large well documented fleet study.

Besides fuel related factors, there are a number of vehicle and climate related issues to consider. Vehicle technology, state of tune, ambient temperatures, head winds, road grade, tire pressure, use of air conditioners, and numerous other factors have an impact on fuel economy. Some of those that have been documented in testing are covered in Table 3-2. Even whether or not the car is level each time you fill it can distort fuel economy readings by several percentage points.

It is easy to see from Table 3-2 why an individual using one or perhaps a few vehicles cannot make an accurate determination of the fuel economy impact of various gasolines. There are simply too many variables.

Through the course of a year, gasoline energy content can range from 108,500 British thermal units (btu) per gallon to 117,000 btu/gal. Winter grades are made more volatile (less dense) to aid in cold start and warm up performance and typically contain 108,500 to 114,000 btu/gallon. Summer grades are of much lower volatility to minimize evaporative emissions and hot start/hot driveability problems. Summer grades will typically contain 113,000 to 117,000 btu/gallons. So the energy content, and therefore the fuel economy, can vary 3.4% to 5.0% just based on the energy content of the fuel. Furthermore comparing the highest energy content summer fuels to lowest energy content winter fuels demonstrates that the variation in energy content is 7.26%. See Table 3-3.

Table 3-2
Factors That Influence Fuel Economy of Individual Vehicles

Factor	Fuel Economy Impact	
	Average	Maximum
Ambient temperature drop from 77˚F to 20˚F	-5.3%	-13.0%
20 mph head wind	-2.3%	-6.0%
7% road grade	-1.9%	-25.0%
27 mph vs. 20 mph stop and go driving pattern	-10.6%	-15.0%
Aggressive versus easy acceleration	-11.8%	-20.0%
Tire pressure of 15 psi versus 26 psi	-3.3%	-6.0%

The lower energy content of winter fuels and the other wintertime influences on fuel economy can easily lead to reductions of 10-20% in miles per gallon during the coldest winter months.

Table 3-3 Gasoline Energy Content
Conventionsal Gasoline - btu Content

	Summer grade btu	Winter grade btu
Maximum	117,000	114,000
Minimum	113,000	108,500
%	3.4	5.0

Difference between summer maximum and winter minimum-7.26%

Oxygenated fuel programs, being wintertime only programs, have therefore been incorrectly blamed for massive fuel economy losses when in fact numerous other variables also contribute to fuel economy losses during winter months.

The reduction in btu/gallon from the addition of oxygenates is generally in the 2% to 2.5% range although fuel economy may not be that much lower. As an example, ethanol contains 76,100 btu per gallon. A 10 volume percent ethanol blend would contain about 3.4% less energy per gallon. However, in controlled tests the fuel economy loss has been far less than would be indicated by the 3.4% lower energy content.

Table 3-4 lists the btu/gallon (energy content) of each of the four oxygenates currently in use and also the energy content of resulting fuels when those oxygenates are blended into a 114,000 btu/gallon base fuel. The 2.0% oxygen level column is typical of reformulated gasoline while a 2.7% oxygen level is representative of gasoline sold in oxygenated fuel program areas.

Table 3-4 Energy Content of Oxygenate Blends
(when blended with 114,000 btu/gallon base fuel)

Oxygenate	Energy content (btu/gal)	Finished blend 2.0 wt.% oxygen btu/gallon	Finished blend 2.7 wt.% oxygen btu/gallon
Ethanol	76,100	111,836	111,082
MTBE	93,500	111,745	110,925
ETBE	96,900	111,811	111,059
TAME	100,600	112,215	111,688

Comparing each of the blends in Table 3-4, you can see that a blend containing 2.0 wt. % oxygen averages just under 2.0% lower energy content. A blend containing 2.7 wt. % oxygen will average about 2.5% lower energy content.

These projected fuel economy variations have been validated in numerous controlled tests and fleet studies. The most recent of these studies, done in 1995, include a fleet test by the State of Wisconsin and a fleet analysis by Lundberg Survey, Inc. The Wisconsin Fleet Survey tested eight vehicles, ranging from 1979 to 1994 models, comparing their fuel economy on conventional gasoline to that achieved on reformulated gasolines containing MTBE, ethanol, and ETBE. The average fuel economy loss for the reformulated gasoline was 2.09%. The Lundberg Survey, analyzing fuel economy complaints in the Milwaukee area RFG market, analyzed the fuel economy of several large fleets totaling thousands of vehicles. The survey compared the fuel economy of these fleets for January 1994 (on conventional gasoline) to January 1995 on reformulated gasoline. The fuel economy loss for these fleets operating on RFG was 1.63%.

These tests and studies combined with numerous others leaves little doubt that the fuel economy loss due to oxygen content is approximately 2.0%.

It should be noted that vehicle technology and state of tune also play a role in fuel economy variations. For instance older vehicles, which operate rich at specified settings may actually show a fuel economy improvement on oxygenated gasolines. This is because the chemical enleanment from the oxygenates results in more complete combustion of the fuel which partially or totally compensates for the slightly lower btu value.

To aid in responding to questions about fuel oxygenates, a "Quick Reference Guide to Facts About Fuel Oxygenates" follows this chapter.

Quick Reference Guide to Facts About Fuel Oxygenates

Fuel oxygenates such as ethanol and methyl tertiary butyl ether (MTBE) continue to experience increased use as motor fuel components. This Quick Reference guide answers some of the most frequently asked questions about fuel oxygenates.

Q: What are fuel oxygenates?
A: Fuel oxygenates are alcohols such as ethanol, and ethers such as MTBE. Most components found in gasoline are made up of hydrogen and carbon (hydrocarbons). Oxygenates are made up of hydrogen, carbon, and oxygen, and therefore add oxygen to the air/fuel mixture, hence the term oxygenates.

Q: Why are fuel oxygenates used in gasoline?
A: Initially oxygenates were added to gasoline to maintain or improve octane quality. While their use as octane enhancers continue, today the focus is on their use as part of the nation's clean air programs. Today, oxygenated fuels are used in wintertime oxygenated fuel programs in over thirty areas of the country. In this application the oxygenates are used for their ability to reduce tailpipe emissions of CO. Oxygenates are also used in reformulated gasoline in ozone non-attainment program areas where their use reduces exhaust emissions of toxics.

Q: How much pollution reduction can be expected from adding oxygenates to gasoline?
A: The level of various pollutants reduced depends on a number of variables such as vehicle technology, type and amount of oxygenate used, and characteristics of the base gasoline. Tests have shown that the CO reduction attributable to oxygenates can range from 10% to 30% depending on vehicle technology. Generally the higher the oxygen content, the greater the level of CO reduction. Toxics reduction attributable to oxygenates ranges from approximately 12% to 17%. These results are achieved because the oxygenates replace less desirable components in gasoline such as benzene, xylene, and toluene.

Q: Are there any other environmental benefits to using fuel oxygenates?
A: Some studies have suggested that renewable fuels, such as ethanol, contribute less to global warming than fossil fuels. This is due to the fact that the ethanol feedstock (primarily corn and agricultural products) absorbs carbon dioxide (CO_2) from the atmosphere when it is grown.

Q: What do the auto manufacturers say about fuel oxygenates? Do they approve of using them in their vehicles?
A: All major auto manufacturers approve of the use of ethanol and MTBE. In fact, some manufacturers, such as General Motors, Chrysler, Ford, Nissan, Range Rover, and Suzuki recommend the use of oxygenated fuels and/or reformulated gasoline. Additional information on auto manufacturer fuel recommendations is contained in Chapter 5.

Q: What about the use of methanol in gasoline?
A: Some vehicle and equipment manufacturers will permit the use of methanol, but most limit the level permitted to 3% or 5% and require special additives. Some will not extend warranty coverage of their fuel systems to cover the use of methanol blends. Methanol is not being used to any degree in today's gasoline and is not permitted in reformulated gasoline.

Q: What is the difference between ethanol and methanol?
A: While both are alcohols, methanol is more sensitive to water than ethanol. It is also not as compatible with vehicle fuel systems as is ethanol. Additionally, while adding 10% ethanol will only increase fuel vapor pressure by 0.5 to 1.0 psi, methanol addition at levels as low as 3% or 4% can increase fuel vapor pressure by 2.5 to 3.0 psi.

Q: Does MTBE contain methanol?
A: MTBE does not contain methanol. Methanol is used in the manufacture of MTBE. However, by converting methanol to an ether, the negative effects (high volatility, questionable materials compatibility, low water tolerance) are eliminated.

Q: How do oxygenates affect fuel system deposits?
A: Today all gasolines, including those containing oxygenates, must meet the same fuel system cleanliness standards implemented by EPA in 1995. Therefore, all gasolines are treated with the type and volume of additive necessary to provide acceptable fuel system cleanliness

Q: Will the cleansing effect of ethanol in the fuel system require fuel filter replacement?
A: Fuel filter replacement depends largely on the age of the vehicle and the extent of deposits in the fuel system. While replacement is not generally required, there are instances where it could be necessary.

(See Chapter 3, page 17-Purolator Service Bulletin-Excerpt)

Q: Have there been any studies on how oxygenates affect driveability?
A: Yes, there have been a number of tests and fleet studies on the effect of fuel oxygenates on vehicle driveability. These studies have generally indicated that the average consumer will detect no difference in vehicle performance. In fact, in some fleet studies, drivers have indicated improved performance from oxygenated fuels. You should not experience any driveability problems on properly formulated gasoline/oxygenate blends.

Q: If oxygenates are acceptable fuel components, why do some auto technicians believe they deteriorate vehicle performance?
A: Auto service technicians do not always have easy access to information on fuel quality. Such a position may indicate that the technician is unfamiliar with fuel quality issues or may not have access to the latest information on the subject. During the period of time that ethanol and MTBE have grown in use, there have been a number of other compositional changes in gasoline. However, many of those changes have not been brought to the attention of the techni-

cian. This results in a perception that the major difference in today's gasolines is oxygenate content when, in fact, many other changes have also taken place.

Q: Have any tests been performed to determine the compatibility of oxygenates with fuel system parts?
A: Yes, several tests have been performed which indicate that oxygenates are compatible with the metals and elastomers in modern vehicle fuel systems.

Q. Will oxygenates result in reduced fuel economy?
A. The addition of oxygenates will result in a fuel economy loss of about 2%. This has been confirmed through numerous tests (See Chapter 3, pages 17 & 18).

Q. Do oxygenates cause vapor lock and hot restart problems?
A. The tendency of a fuel to contribute to vapor lock and hot restart problems is defined by its overall volatility characteristics. This includes the fuel's distillation characteristics, vapor pressure, and vapor liquid ratio. Vapor lock and hot restart problems are primarily a summertime problem. Today the summertime volatility of all fuels, including those containing oxygenates, is controlled by EPA volatility regulations. Consequently, hot driveability problems related to fuel volatility have been largely eliminated. (See Chapter 1, pages 5-6 and Chapter 3, pages 15-16).

Q. What about complaints concerning the odor of oxygenated gasoline?
A. Oxygenates can be either an alcohol such as ethanol or ethers such as MTBE and ETBE. The ethers have a distinct ether smell when added at higher levels. Some motorists may find the odor not only noticeable but unpleasant. However, the ether vapors are less harmful than other gasoline vapors such as benzene and other aromatics.

Q: What about using oxygenated fuels in power equipment and other small engine applications?
A: Nearly every mainstream manufacturer has indicated that oxygenated fuels, such as those containing ethanol or MTBE, can be used in their products. A small number of manufacturers indicate that minor adjustments may be necessary or recommend special precautions. (See Chapter 6).

Chapter 4 Fuel System Deposits Fuel Quality Testing

Fuel System Deposits

Perhaps the fuel quality issue currently receiving the greatest attention is the deposit tendencies of today's gasolines. Actually, today's gasolines are, in many ways, higher in quality than gasolines of the past. Volatility is more in line with vehicle design. Blended fuels undergo more stringent quality control procedures and many fuels contain extensively developed additive packages to improve fuel quality.

In many ways, today's automobiles can handle a broader range of fuel variables. But this is not always the case. A good example of this is the fuel metering system. The fuel injection systems in late model vehicles are incredibly precise compared to a carburetor or even a throttle body injection (TBI) system. At the same time, these systems are also more sensitive to, and easily affected by, deposit formations. This, in combination with increases in intake valve deposits (IVD) and induction system deposits (ISD), has caused a great deal of attention to be focused on this area.

Properly formulated gasolines play an important role in minimizing deposits in carburetors, fuel injectors, intake valves, and the entire fuel induction system.

The 1990 Clean Air Act Amendments included a requirement that <u>all</u> gasoline sold after January 1, 1995 must "contain additives to prevent the accumulation of deposits in engines or fuel supply systems". The EPA has issued regulations to govern the use of such additives and to ensure that they are effective at controlling deposits in carburetors and fuel injectors as well as on intake valves. These regulations apply to oxygenated and reformulated gasolines as well as conventional gasoline. The EPA is also considering standards for control of combustion chamber deposits but has not yet adopted guidelines due to the lack of a standardized test to measure performance.

The requirement for all gasolines to contain detergents and/or deposit control additives has greatly reduced the debate about which gasoline components contribute to deposit formation. Additives must now be tested for their effectiveness for use in the gasolines for which they are registered with EPA.

Control of fuel system, induction system and combustion chamber deposits was deemed necessary because excessive deposits can increase exhaust emissions of HC, CO, and NO_x. However control of such deposits will also reduce related driveability complaints.

It appears these regulations will solve many deposit problems. However, we are in somewhat of a transitional phase where some technicians are still encountering PFI and intake valve deposits. Because of this we continue to provide an abbreviated overview of past and present deposit related issues for technicians who may not have earlier versions of "Changes in Gasoline".

Carburetors/Throttle Body Injection: Carburetors and throttle body injectors (TBI) are relatively unsophisticated when compared to Port Fuel Injection (PFI). With the majority of cars on the road today being PFI equipped, the focus on deposit control treatment is directed at that technology. Additives that control PFI deposits will easily control carburetor or TBI deposits.

PFI Deposits: In the mid 1980s auto manufacturers began a major move to switch to port fuel injection. During that time frame there were problems with deposit fouled injectors.

A deposit-fouled injector will result in an uneven spray pattern. The more severe the reduction in flow, the more severe the symptoms. Fouled injectors can result in uneven idle, reduced power, poor fuel economy, hard starting, increased emissions and even stalling, particularly if the computer control system can no longer correct for insufficient fuel flow.

Automakers generally agree that any reduction in fuel flow beyond 10 percent, on any individual injector, will result in some occurrence of the problems mentioned above, particularly in sensitive vehicles.

There was a great deal of debate about the causes of injector pintle deposits. It was ultimately shown through numerous tests that there were a number of contributing factors (see Table 4-1), the most important of which was driving pattern.

Deposit formation occurs during the hot soak period immediately after the engine is shut off. Therefore, typical city short trip driving tends to increase port fuel injector deposit formation.

The design and tolerance of the injector itself plays a role in deposit formation. Pintle type fuel injectors have been shown to be more prone to deposit formation. In these injectors, the fuel injector flow-control pintle is manufactured to very exacting tolerances. The metering orifice opening is approximately 0.002". Additionally the pintle itself provides a surface on which deposits may form.

Some tests have shown that fouled injectors can be removed, cleaned and reinstalled at different cylinder locations and will continue to exhibit similar deposit tendencies. This would seem to indicate that the injector itself may be a significant contributor to the problem in some instances.

Also, a non-specification injector or metallic deposits may be suspected if detergent cleanup procedures fail to restore an injector to its proper operation.

Deposits do not form at the same rate in all engines or all injectors in the same engine. Some tests indicate that higher temperatures may lead to increased deposits.

Fuel weepage may also play a role in deposit formation. Port fuel injected systems remain under pressure even when the engine is shut down. An injector pintle that is not seating properly may allow fuel to weep (pass fuel beyond the injector seat) during hot soak.

Finally, there is the issue of fuel composition and detergent treatment, Tests have shown that olefins and diolefins are the gasoline components most likely to contribute to increased PFI deposits. In fact, in 1985 General Motors sent letters to the major oil companies discussing the PFI fouling problem and indicated that "Investigations by GM and others indicate that high gasoline olefin content and the lack of sufficient quantities of appropriate detergents and oxidation inhibitors contribute to the problem." Olefin content had risen during this time frame as refiners struggled to maintain octane quality while reducing the use of lead. Also during this time frame not all gasolines were adequately treated with appropriate detergents.

Table 4-1 Factors Contributing to PFI Deposits

Driving pattern - Frequent extended hot soaks

Injector design - Pintle vs. pintle-less

Temperature/heat

Fuel weepage

Fuel composition - Olefins/diolefins

Insufficient detergent treatment

During this era of PFI deposit problems reformulated gasolines were not yet available. Oxygenated fuels were widely available but tests indicated that they were not a major contributing factor to PFI fouling.

Of course, today, the issue of "sufficient quantities of appropriate detergents" is addressed through the EPA regulations. Even without such regulations at the time, the majority of the fuels industry moved quickly to reformulate additive packages and treat rates to address PFI fouling. In addition the automakers and their original equipment manufacturers (OEMs) designed injectors that were less prone to deposit formation. As an example GM introduced the "Multec" port fuel injector which is of a pintle-less design. Others have also introduced pintle-less injectors.

Though widely reduced through the use of detergent gasolines, technicians may still occasionally encounter deposit fouled port fuel injectors. Corrective action (other than replacement) is limited to aerosol cleaners such as those from BWD, Champion, NAPA, and 3M or in-tank additive treatments such as GM's Top Engine Cleaner, Chevron's Techron, and similar products. The aerosol cleaners contain a detergent which can be effective in removing deposits from fouled injectors. The technician is advised, however, that some manufacturers recommend against the use of aerosol cleaners for certain injectors and should be aware of each manufacturer’s position. For instance, GM has advised their service network that some fuel injector cleaners may contain high levels of methanol and other solvents that cause damage to the Multec injector’s coil wire insulation. GM maintains a position that Multec port fuel injectors should not be cleaned (GM Dealer Service Bulletin 91-312-6E). In-tank additive treatments contain a clean up dose of detergents that can clean fuel injector deposits and may reduce intake valve deposits. Instructions for these additives should be followed closely. Some auto manufacturers recommend changing oil after using such clean up treatments since additive overtreatment may lead to oil thickening.

Induction System Deposits: With PFI deposits reduced dramatically, attention was next focused on intake valve deposits (IVD) and other induction system deposits (ISD). Figure 4-1 depicts both PFI and intake valve deposits and their consequences. The symptoms of IVD are often diffcult to distinguish from PFI deposit symptoms.

Tulip and port deposits affect the in-cylinder flow characteristics of the air/fuel charge. Also, when the vehicle is started cold, these deposits absorb fuel from the air/fuel mixture until they are saturated. This results in a lean operating condition while the vehicle is in the warm up mode.

Compared to PFI deposits, the formation and extent of IVD is more difficult to assess. They are also more difficult to remove or prevent.

Figure 4-1
Impact of Deposit Formation in Modern Engines

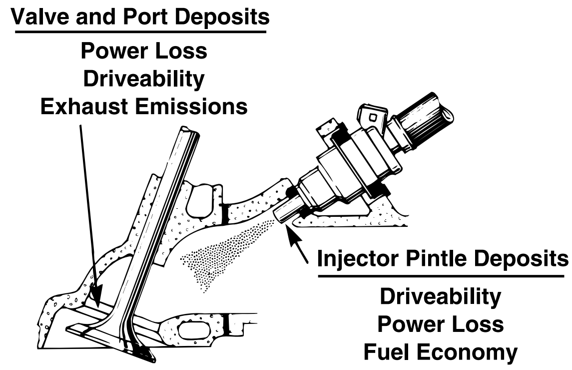


Photo courtesy of Chevron Research Company

Valve deposits have, of course, always been present in the internal combustion engine. In older vehicles, these deposits were of a gummy nature and were more a result of the engine oil. Today's engines have much tighter tolerances and the valves are exposed to less oil. The IVD in today's engines are of a harder, more carbonaceous make up and appear to be more fuel related.

The problem does not affect all engine configurations to the same degree and is generally more prevalent in vehicles which operate leaner in the warm up mode.

There are several factors that contribute to IVD (see Table 4-2).

Table 4-2
Factors Contributing to IVD

Engineering Factors

- Operating temperature
- Heat retention of valve
- Angle of spray pattern to valve
- Engine control technology (EGR rate)

Fuel Related Factors

- Gasoline composition
- Detergent chemistry

Operational Factors

- Driving pattern (short cycles)
- State of tune

Engineering considerations include engine operating temperature (hotter temperatures increase IVD), the angle of injector spray in relationship to the valve tulip, and engine control technology. Vehicles with EGR systems are more prone to deposit formation.

Fuel related factors include gasoline composition, with olefins being suspected of increasing IVD. Also, the detergent chemistry may play a role. Some detergents are relatively neutral in IVD formation while some have been shown to increase IVD, in some vehicles, under certain operating conditions. Additionally, latest-generation deposit control additives have been shown to control or minimize IVD. However additives that control IVD are now necessary to meet EPA's detergent regulations. These additives may also help reduce performance-robbing combustion chamber deposits which can contribute to octane requirement increase (ORI).

Several deposit control additives have also been shown to be effective at controlling the deposit characteristics of oxygenated fuels and reformulated gasolines although the proper treat rate may vary compared to non-oxygenated fuels.

Once again, driving pattern plays a role with IVD appearing to be more prevalent in vehicles used on short trip driving cycles due to more frequent hot soak cycles.

The petroleum, automotive, and additive industries have conducted extensive work to develop standardized industry tests to measure the deposit control characteristics of gasoline and additive treatment packages. In turn, this has enabled industry to constantly improve its additive packages.

While the EPA regulations require that today's gasolines be properly treated to minimize IVD this is a recent development. Technicians may encounter vehicles that developed deposit build-up prior to these regulations. Additionally, some vehicles driven on repetitive short cycle trips may still develop deposits that cannot be adequately controlled by additives.

Once deposits reach levels that degrade vehicle operation, corrective action is required. One of the more common corrective measures is to use a walnut shell-based carbon blaster. This procedure utilizes compressed air to force ground walnut shells across the valve (while still in place in the engine). It has proven to be an effective method for removing IVD.

Some additive manufacturers have indicated that their aerosol/liquid PFI cleaners are also effective at cleaning IVD. However, some auto manufacturers seem to be in disagreement with this claim. GM has indicated that "…General Motors laboratory tests have shown that injector cleaners have little or no effect on intake valve deposits." This issue remains unresolved.

There are also "over-the-counter" additives available that provide a "clean up" treat rate to reduce fuel injector and intake valve deposits. Some chemistries are also claimed to reduce combustion chamber deposits. There are a variety of such additives on the market and the advertising claims should be thoroughly assessed. Some additives are simply fuel injection cleaners while others address the entire induction system.

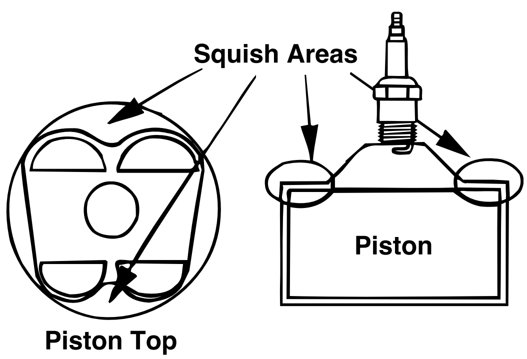
Vehicle owners with IVD sensitive vehicles, and especially those who drive predominantly short driving cycles, may wish to consider using such after-market additives. One after-market additive frequently recommended is Chevron's Techron®. Additives employing chemistry similar to Techron® are also available from many of the auto manufacturers through their parts distribution system.

Auto manufacturers' recommendations regarding the use of after-market gasoline additives should be reviewed. Indiscriminate or excessive use of such additives could lead to other problems such as elastomer degradation or oil thickening.

Combustion Chamber Deposits: Additive development has led to chemistries which control PFI deposits and IVD. Consequently, the area of focus has rapidly moved to Combustion Chamber Deposits (CCD)

CCD has been shown to increase the octane requirement of an engine. More recently another problem called Combustion Chamber Deposit Interference (CCDI) has been observed in engines with a nominal squish height of 0.7 to 1.0 mm (squish height is the distance between the cylinder head and piston squish areas at top dead center). CCDI causes a "knocking" type of noise when the deposits on the piston squish area build up and cause contact with deposits on the cylinder head (see Figure 4-2).

Figure 4-2



As with other deposits, there are a number of variables and contributing factors involved in assessing CCD formation. Further, it is not yet clear if all contributing factors have been identified or if those identified are totally understood. Thus far it is known that oil consumption is a factor because some materials identified in the deposits are only present in lubricants. Also IVD plays a role because these deposits may distort the combustion flame resulting in a larger fraction of molecules condensing on the combustion chamber surface. The higher boiling components of fuel, lubricants, or additives may also play a role. Due to vaporization and chemical interaction between molecules these components may lead to a film, sometimes referred to as the "fly paper affect". This film then traps various other constituents thereby growing in thickness finally forming a lacquer type deposit.

Research on CCD and CCDI is ongoing. Additionally, EPA hopes to develop regulations that will require additives that control or minimize CCD.

Fuel Testing

Sale of gasoline that is "out of spec" or "sub quality" is a very rare occurrence. Since the technician is often contacted when there is a problem with the fuel, the occurrences seem far more frequent than they really are in proportion to the total amount of gasoline sold. When one considers that over 325 million gallons of gasoline are sold in the U.S. each and every day, it is easy to see that well over 99% of the gasoline sold performs satisfactorily in the vehicle population.

In those isolated instances when poor fuel quality may be contributing to driveability and performance problems, it is beneficial for the service technician to know what avenues are available to assess fuel quality.

Many of the tests to determine fuel quality are outside the capabilities of the auto service shop. Tests such as octane, distillation, and detergency require special equipment, some of which is very expensive.

Figure 4-3
Alcohol Detection Test

Lower phase dyed for photographic purposes.

Some field kits are available to measure certain properties although test results are often of limited value. Fuel standards are performance-based standards. They define how the fuel should perform, not what it should contain. The presence, or absence of any fuel component is not an indication of whether or not the fuel meets performance-based standards.

Most kits include an alcohol detection test. The presence of alcohol in gasoline can be determined by the "Water Extraction Method." A graduated glass cylinder, usually 100 milliliters (ml), is used for the test. The procedure is as follows:

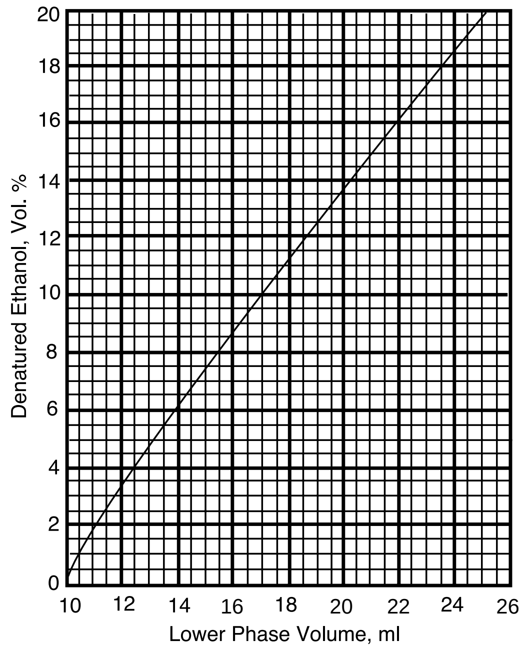
Place 100 ml of gasoline in a 100 ml stoppered glass graduated cylinder. Add 10 ml of water into the cylinder and shake thoroughly for one minute. Set aside for two minutes. If no alcohol is present, the 10 ml of water will settle to the bottom of the graduated cylinder. If alcohol is present the alcohol will drop to the bottom, along with the water, increasing the bottom layer to greater than 10 ml. The amount of increase depends upon the amount of alcohol present. (See Figure 4-3)

The graph in Figure 4-4 (page 24) assists in calculating the approximate alcohol content when using the water extraction test. Simply determine the volume of the lower phase (bottom scale). The line that crosses that point on the graph provides the volume of ethanol as listed on the left side of the graph.

For instance, a reading of approximately 17 ml in the lower phase indicates a presence of approximately 10% alcohol. Although this test identifies the level of alcohol present with a reasonable amount of accuracy, it does not identify the type of alcohol. This presents a problem because identification of the presence of 10 volume % alcohol would be acceptable if the alcohol were ethanol. On the other hand, if the alcohol were methanol, 10 volume % would be an illegal blend and a blend not covered under vehicle warranty. Properly formulated, a 10 volume % ethanol blend would not typically result in driveability problems, whereas a 10 volume % methanol blend would likely have an excessively high vapor pressure and contain too much oxygen for proper vehicle operation. Additionally, this test does not identify the presence of ethers such as MTBE. More importantly, this test gives no indication of the fuels volatility, octane, or other characteristics.

One test that would help define performance based standards is the vapor pressure test. Some technicians have tried to develop "home-made" vapor pressure testers. Some

Figure 4-4 Volume Percent of Denatured Ethanol in Gasoline-Water Extraction Method



test kits may also include such devices.

A vapor pressure tester must be manufactured to very exacting specifications in order to replicate ASTM test procedures. In some cases, the precision of such devices has been called into question. Additionally, it is very difficult to maintain the test conditions necessary to obtain accurate readings outside of a laboratory environment. Therefore, if you are utilizing a vapor pressure testing device you should try to determine if, in fact, the equipment will provide accurate readings on a repetitive basis. You should ensure that you are closely following all instructions and test procedures specified for the testing device. Unfortunately, performing a vapor pressure test under field conditions does not always yield an accurate reading.

Figure 4-5 BWD Specific Gravity Hydrometer

Fuel test kits are also available to test the specific gravity of gasoline. Specific gravity provides a directional assessment of a fuels overall volatility and its energy content. The kit shown in figure 4-5 is available from BWD Training Division.

To test specific gravity with this kit, you simply fill the graduated cylinder with 40ML of fuel and insert the hydrometer into the cylinder. Place the cylinder on a level surface, allow the hydrometer to stabilize and read specific gravity. Temperature correction tables are provided with the kit to adjust for temperature variation in the fuel.

Higher specific gravity indicates denser fuel, lower specific gravity indicates less dense fuels. BWD indicates that fuels of less than 0.730 specific gravity are more prone to cause driveability problems. Generally speaking, fuels of lower specific gravity are more volatile although this does not necessarily correlate with vapor pressure tests. The specific gravity also gives some indication of btu content. The higher the specific gravity the greater the btu content of the fuel. The graduated cylinder in the kit can also be used to perform the alcohol separation test.

None of these tests measure octane or distillation which are really the most important properties. Therefore, results from these tests do not necessarily isolate fuel problems and should be viewed simply as screening tests.

Laboratory tests are, of course, far more accurate and test a broader range of properties. There are potentially two ways that a service technician might be able to obtain laboratory tests with little or no cost. Tests can be performed by the fuel supplier or a regulating state agency.

Gasoline marketers live on repeat business and suffer sales losses if their fuels do not perform satisfactorily. It is in their own best interests to identify any problems. If a customer with a suspected fuel related problem generally purchases all of their gasoline at the same station, you might try contacting that station or their supplying company's representative. Sometimes these companies will have laboratories or contract testing arrangements and may be able to perform tests necessary to identify any deviation from fuel specifications.

Additionally, many states have programs that monitor fuel quality on either an ongoing or "incident specific" basis. The majority of these programs are operated by a state's Department of Weights & Measures. In some instances, there may be a separate agency or division for petroleum product inspection and enforcement. If your state has such a program you might wish to contact them if you suspect off-specification fuel.

Keep in mind that the funding for these programs varies dramatically from state to state. Consequently their response capabilities and testing abilities also vary.

You should keep in mind fuel related problems are seldom a single vehicle incident. One of the first clues that a problem is fuel related, is a rash of similar complaints involving a variety of different vehicles. When an “off-spec” fuel makes it through the system, it will affect a variety of vehicles in a very short period of time.

Before contacting a supplier or regulatory agency about a suspected fuel problem, you should be reasonably certain that the fuel is, in fact, a contributing factor. You should also be able to provide details such as the date, approximate time, and the location of the fuel purchase.

Table 4-3 lists each state and, where known, the name and phone number of the agency or governmental division charged with regulating gasoline quality.

For states without formal petroleum inspection programs you might want to check with the consumer protection division to determine if any other course of action is available.

Table 4-3 State Motor Fuel Agencies

Alabama	AL Weights & Measures Division	334-242-2614
Alaska	AK Dept. of Environmental Conservation	907-465-5100
Arizona	AZ Dept. of Weights & Measures	602-255-5211
Arkansas	AR Bureau of Standards	501-324-9680
California	CA Measurement Standards	916-229-3060
Colorado	CO State Oil Inspection	303-289-5643
Connecticut	CT Weights & Measures	860-566-5230
Delaware	DE Div. of Motor Fuel Tax	302-739-4538
Dist. of Columbia	No program	
Florida	FL Dept. of Ag & Cons Service	904-488-0645
Georgia	GA Dept. of Agriculture	404-363-7597
Hawaii	HI Measurement Standards Division	808-586-0871
Idaho	ID Dept. of Agriculture	208-344-2345
Illinois	IL Weights & Measures Bureau	800-582-0468
Indiana	IN Dept. of Weights & Measures	317-383-6350
Iowa	IA Dept of Ag Weights & Measures	515-281-5716
Kansas	KS Weights & Measures	913-267-4641
Kentucky	KY Division of Weights & Measures	502-564-4870
Louisiana	LA Dept. of Transportation	504-929-9153
Maine	ME Dept. of Agriculture-Div. of Regulations	207-287-3841
Maryland	Motor Fuel Test Lab	410-799-7777
Massachusetts	MA Division of Standards	617-727-3480
Michigan	MI Dept. of Agriculture	517-373-1060
Minnesota	MN Dept. of Public Srv.-Weights & Measures Div.	612-639-4010
Mississippi	MS Dept. of Ag. & Commerce	601-354-6202
Missouri	MO Dept. of Agriculture	314-751-2922
Montana	No program	
Nebraska	No program	
Nevada	NV Dept. of Business & Industry	702-688-1180
New Hampshire	No program	
New Jersey	NJ Weights & Measures	908-815-4840
New Mexico	NM Dept. of Agriculture	505-646-1616
New York	NY Dept. of Agriculture & Markets	518-457-3146
North Carolina	NC Dept. of Agriculture	919-733-3246
North Dakota	ND Health & Consolidated Labs	701-221-6149
Ohio	No program	
Oklahoma	Fuel Inspection Division	405-521-2487
Oregon	No program	
Pennsylvania	No program	
Rhode Island	RI Tax Administration	401-277-3050
South Carolina	SC Dept. of Agriculture	803-737-2070
South Dakota	No program	
Tennessee	TN Dept. of Agriculture	615-360-0147
Texas	No program	
Utah	UT Dept of Ag-Gas Lab	801-538-7159
Vermont	VT Dept. of Ag-Consumer Assurance Section	802-828-2436
Virginia	Office of Products & Industry Standards	804-786-2476
Washington	WA Dept. of Ag-Weights & Measures	360-902-1857
West Virginia	Div. of Labor-Weights & Measures	304-722-0602
Wisconsin	Bureau of Petroleum Inspection	608-266-7605
Wyoming	No program	

Fuel Recommendations

Despite limited methods to assess fuel quality, technicians are often requested to offer recommendations on gasoline either by brand, type, octane rating, or some other characteristic.

First and foremost, the consumer should follow the recommendations contained in their vehicle owner's manual.

The octane of the gasoline should meet the minimum specified in the fuel recommendations section of the vehicle owner's manual for the applicable vehicle. A higher octane gasoline should be selected if ongoing engine ping is experienced when operating on the recommended octane level (assuming mechanical causes have been eliminated).

Today, with all gasolines required by regulation to contain effective detergents and deposit control additives, there is less necessity to direct consumers to gasoline advertised as containing such additives. If, despite the use of detergent gasolines, consumers are still experiencing deposit problems (for instance as a result of repetitive short cycle trips) it may be beneficial to occasionally add an "over-the-counter" deposit control additive. If such after market additives are utilized, the manufacturer's recommendations regarding the use of such products should be followed.

Consumers should also be informed about the pitfalls of storing gasoline for extended periods. Long storage periods could result in the use of summer fuel in the winter or vice versa. The resulting improper volatility could lead to driveability problems. Fuel stored for extended periods also weathers, leading to a loss of volatility which can contribute to poor cold start and warm up performance. Finally, fuels in storage for long periods begin to deteriorate and can lead to greater fuel system/engine deposits.

If the vehicle is being placed in storage for extended periods and the fuel system is not being completely drained the gasoline should be treated with a fuel stabilizer to extend its storage life. Examples of such products include STA-BIL and Napa's Store It-Start It. Similar products are also available from other companies.

Beyond these basic recommendations, it is difficult to differentiate between fuels. Obviously, if a consumer experiences driveability problems that are suspected of being fuel related, they should switch to a different gasoline to see if driveability improves.

Chapter 5 Auto Manufacturers' Fuel Recommendations

To inform vehicle owners about fuel quality and fuel ingredients, automobile manufacturers place statements in their owner's manuals concerning octane and fuel components such as alcohols, ethers, and in some cases, detergent additives.

While octane is a fairly straight forward recommendation, there has been some confusion regarding the use of oxygenates. This is in part due to consumers (and in some cases service technicians) not understanding the difference between ethanol, which is approved for use, and methanol, which is often not approved for use. Further, some consumers assume that MTBE contains methanol which is incorrect.

When oxygenates first began to see widespread use in gasoline, some auto manufacturers included strong precautionary wording regarding their use. This was due to concerns about quality control of the blending process and, despite favorable test results, a general lack of field experience with these fuels. As more experience was gained and quality control improved, these precautionary statements were dropped by most automakers.

Today all auto manufacturers approve of the use of oxygenated fuels. The degree of approval varies among manufacturers. Some still use mild precautionary wording such as recommending a return to conventional gasoline if you are not satisfied with the performance of an oxygenated fuel. Many manufacturers simply state that ethanol and MTBE are approved for use. A number of auto manufacturers now recommend the use of oxygenated gasoline/reformulated gasoline. For instance, GM, Ford, Chrysler, Nissan, Range Rover, and Suzuki all recommend the use of oxygenated fuels and/or reformulated gasoline. Some have also issued bulletins or notices applying their approved use of oxygenated fuels to earlier model years. Examples include Nissan which issued such a bulletin on 12/14/89. BMW has advised that their current model year recommendations apply to all model years designed to operate on unleaded gasoline. GM has gone perhaps the furthest in this regard stating that you can begin using reformulated gasoline "…in any GM car or light duty truck. Any model. Any year. You'll never notice the difference."

Table 5-1
Auto Manfacturers' Fuel Recommendations Recap (based on 1995 model year owner's manual)

Manufacturer	Approves of ethanol	Approves of MTBE	Approved methanol limits*	Precautionary language for oxygenates	Recommends or approves RFG	Recommends detergent gasoline	Precautions on use of after market additives
Chrysler	yes	yes	no	x	yes	yes	yes
Ford	yes	yes	5%	(1)	yes	yes	x
GM	yes	yes	5%	x	yes	yes	x
BMW	yes	yes	3%	x	x	yes	x
Honda/Acura	yes	yes	5%	x	x	x	x
Hyundai	yes	yes	no	(1)	x	yes	x
Isuzu	yes	x	5%	(2)	x	x	x
Jaguar	yes	yes	3%	(1)	x	x	x
Mazda	yes	x	no	(1)	x	x	yes
Mercedes Benz	yes	yes	3%	x	x	yes	yes
Mitsubishi	yes	yes	no	x	yes	yes	x
Nissan/Infiniti	yes	yes	5%	(1)	yes	x	yes
Porsche	yes	yes	---	(1)	x	x	x
Range Rover	yes	yes	5%	x	yes	yes	x
Rolls Royce	yes	yes	3%	x	x	x	x
Saab	yes	yes	5%	x	yes	yes	x
Subaru	yes	yes	5%	x	yes	yes	x
Suzuki	yes	yes	5%	(1)	yes	x	x
Toyota/Lexus	yes	yes	5%	(1)	x	yes	x
Volkswagen/Audi	yes	yes	3%	(1)	x	yes	yes
Volvo	yes	yes	no	x	x	x	x

* Requires equal amounts of cosolvents, plus corrosion inhibitors be used in the fuel.
(1) Mild precautionary wording (2) Strong precautionary wording x No references made in owner's manual

While many manufacturers have deleted precautionary language statements about fuel oxygenates, some manufacturers now recommend that if you experience a driveability problem you suspect is fuel related, you should try a different brand or grade of fuel before seeking service (e.g. Chrysler, Ford, BMW, Mitsubishi, Saab, Subaru).

Earlier versions of this manual have always included the exact fuel recommendations of the manufacturers, exactly as printed in the vehicle owner's manual. With all manufacturers clearly approving of the use of fuel oxygenates and reformulated gasoline, it is somewhat redundant to include this information once again. At the same time we believe a recap of each manufacturer's position is important. For that purpose we have provided Table 5-1. The table lists each manufacturer that markets in the U.S. on a nationwide basis. Each manufacturer's position on ethanol, MTBE, and methanol is listed. Also noted are any precautionary statements regarding the use of oxygenates or over-the-counter additives as well as whether or not the manufacturer recommends the use of RFG and detergent gasolines.

Most manufacturers have not yet included wording addressing other oxygenates such as ETBE and TAME. Some, such as Chrysler and Range Rover, do mention that ETBE is approved. In general, auto manufacturers do not anticipate that TAME or ETBE will perform any differently than MTBE. However these ethers are not yet widely used so most manufacturers have not felt a need to mention them in their vehicle owner's manuals.

The information contained in Table 5-1 is based on a review of the fuel recommendations section for 1995 model year vehicles. Individual models are not listed since fuel recommendations are normally consistent across a manufacturers product line (e.g.the statements concerning these fuels in a Buick owner's manual are the same as for other GM models etc.).

You will note that all manufacturers approve of the use of ethanol by specific mention and all but two, Isuzu and Mazda approve of MTBE by specific mention.

While Table 5-1 replaces the exact owner's manual wording contained in earlier editions of the manual, Downstream Alternatives Inc. continues to maintain a data base of the exact wording used.

To obtain a complete copy of Downstream Alternatives Inc.'s Automotive Manufacturers Fuel Recommendations database, send your request along with US $2.00 (to cover copying and postage) to Downstream Alternatives Inc. • P.O. Box 2587 • South Bend, IN 46680-2587. Please include a self addressed mailing label.

Chapter 6 Oxygenated and Reformulated Gasolines in Power and Recreational Equipment

Background

Over the past dozen or so years there has been a great deal of confusion about the use of oxygenated fuels in various non-automotive applications. Programs requiring the use of oxygenated fuels and reformulated gasoline have heightened interest in this topic.

Service technicians often receive questions about the use of these fuels in applications other than the automobile. Additionally several power and recreational equipment manufacturers and small engine service/repair personnel have now started using our "Changes in Gasoline" manual. Accordingly, we felt it appropriate to add this chapter to the manual to provide information on this topic.

First it should be noted that all gasoline, whether oxygenated or not, is designed for its primary intended use, the automobile. In fact, the standard industry specification for gasoline is titled *Standard Specification for Automotive Spark Ignition Engine Fuel*. Little consideration is given to the needs of the small engine manufacturer and they find themselves designing around whatever fuels are made for automotive use.

Manufacturers of gasoline powered non-automotive equipment fall into one of four general categories. These include motorcycles, boats, recreational equipment (snowmobiles and ATVs), and lawn/garden power equipment.

Manufacturers in these four categories have various fuel related issues when designing their products or when developing recommendations for their use. For instance, all of these categories are usually subject to seasonal use and extended storage periods. Gasoline deteriorates in storage which tends to contribute to more engine deposits and gumming of carburetors and fuel injectors. Therefore, most manufacturers recommend either draining all gasoline, or treating it with a fuel stabilizer, when equipment is to be stored for long periods. Additionally, compared to an automobile, much of this type of equipment is relatively inexpensive and consumers do not exercise the same degree of care that they would with the family car.

Since boats operate, and are often stored in, a marine environment, fuel moisture content is an issue. Snowmobiles and equipment used in extreme cold often specify rich air/fuel ratio settings and the engines in such equipment may be sensitive to enleanment. Lawn and garden equipment is often designed to be light weight for ease of handling. Consequently, the fuel systems of such equipment may be fitted with different metals, plastics, and elastomers than those utilized in an automobile's fuel system. The lawn and garden equipment category is also subject to the greatest degree of consumer neglect, since it is usually relatively inexpensive.

Manufacturers are currently confronted with a growing amount of environmental regulations designed to lower emissions from their products. These regulations are in addition to an extensive array of laws pertaining to noise levels and safety.

Consequently then, these manufacturers are confronted with the need for extremely low production costs, specialized considerations, and limited research and development budgets. Yet they must produce equipment that is safe, reasonably quiet, durable, consumer friendly, capable of operating on today's fuels, and with increasingly lower exhaust emissions.

Initially, during the early 1980s, the predominant oxygenate was ethanol. During this time frame, gasoline ethanol blends comprised only a few percent of the gasoline marketplace and were viewed as somewhat of a novelty. Small engine/equipment manufacturers were slow to conduct tests on a fuel with limited marketshare and an uncertain future. Little technical data about the use of gasoline ethanol blends was available and, of course, there was little field experience upon which to base decisions regarding its use in such applications. These factors led to the majority of manufacturers recommending that gasoline ethanol blends not be used in their products.

By the mid 1980s manufacturers began to indicate that gasoline ethanol blends could be used in their products provided certain storage precautions were followed. The degree of approval often varied with some simply stating ethanol blends could be used while others stated such use was permitted but not recommended.

Oxygenated Fuel Issues

Past concerns expressed by equipment manufacturers fall into five categories. These include materials compatibility (i.e. metals, plastics, & elastomers), lubricity, enleanment, and storage considerations (phase separation, fuel stability). Some manufacturers have also expressed concerns about over-blends (i.e. blends containing more than legally permitted levels of approved oxygenates). The following provides more detail on each topic.

Materials Compatibility: The two predominant fuel oxygenates, ethanol and MTBE, have been extensively tested for their effects on various metals, plastics, and elastomers. Such tests have included both controlled laboratory testing as well as field demonstration projects. Some equipment manufacturers have also conducted tests on their specific equipment. In the early to mid 1980s, some manufacturers did find it necessary to upgrade a few of the materials used in their fuel systems. Whether or not this was necessitated by the use of alcohols and ethers is sometimes uncertain because the aromatic content of gasoline was also increased during the same time frame. Since aromatics also effect elastomer durability, this may have contributed to isolated problems. In any event, manufacturers now use upgraded materials that are largely unaffected by properly formulated oxygenated fuel formulations. This is evidenced by their fuel recommendation comments which now permit the use of such fuels. Further, responsible aftermarket suppliers provide only replacement parts that are designed for use with oxygenated fuels. As an example, Walbro Engine Management Corp., a major supplier of carburetor rebuild kits and other parts, has indicated that Walbro parts are resistant to alcohol-related decomposition as long as the volume of alcohol is within legal limits.

Lubricity: In the past, some manufacturers, especially of two stroke engines/equipment, have expressed concern that gasoline ethanol blends may not provide adequate lubricity. There is no technical data to support such a position. In fact, the limited data available indicates that properly formulated gasoline ethanol blends may provide slightly better lubricity.

Enleanment: Oxygenates chemically enlean the air/fuel (A/F) mixture. As an example, in engines set at an A/F ratio of 14.7:1 on all hydrocarbon fuel, the introduction of 2.7% oxygen in the fuel would enlean the A/F ratio to about 15.15:1. Computerized vehicles can compensate for this shift by sending a command to increase fuel flow. Most non-automotive equipment is not sophisticated enough to accomplish this. However, this small change in air/fuel ratio is not of concern in most equipment and usually no modifications are required. Some manufacturers have expressed concern that the enleanment resulting from fuel bound oxygen could create problems in certain severe applications. In particular, there is concern about continuous operation at wide open throttle (WOT) such as in marine applications. Also of concern is equipment that typically operates rich at specified settings. An example here would be snowmobiles. The two primary concerns are octane quality and excessive heat. Properly blended oxygenated fuels should not present problems in the area of octane quality because oxygenates are actually octane enhancers. Outside mandated program areas, oxygenates, such as ethanol and MTBE, are routinely used to improve the octane quality of gasoline. The more predominant concern is the potential for higher operating temperatures. The maximum combustion temperature (and resulting engine temperature) occurs at an air/fuel ratio of 14.7:1. Going rich or lean from this point will result in lower temperatures. Therefore, equipment with richer initial A/F ratio settings such as 13 or 14 to 1 may experience increased operating temperatures when switched to oxygenated fuels. This increase is not significant and most manufacturers do not require any modifications, but some do. For instance, Polaris recommends that their carbureted sleds "jet up" one size when operating on oxygenates. Further, their fuel injected 2 cylinder model requires a "shim kit" to lower the compression ratio. Polaris fuel injected 3 cylinder models are computerized and the E-Prom is already calibrated to compensate for changes in oxygen content. Arctco recommends that when using oxygenated fuels in their Tiger Shark Watercraft, the high speed needle valve should be "opened" 1/8 of a turn from its setting. In the case of their Arctic Cat sleds, they recommend "jetting up" the carburetor jets one size. Only a handful of marine and recreational manufacturers offer such recommendations but consumers should be advised to consult their owner's manual or servicing dealer to determine if any modifications are recommended.

Storage Considerations: Phase separation concerns pertain primarily to alcohol based oxygenated fuels. Alcohols attract moisture. If excessive moisture is absorbed, the alcohol and water can phase separate (fall out of suspension) from the gasoline blend. This would result in a mixture of alcohol and water in the bottom of the fuel tank. Aside from the fact that the engine would not operate on this alcohol/water blend, it can also cause corrosion of various metals it comes in contact with. However the potential for phase separation must be put in perspective. As noted in Chapter 3, it would take almost four teaspoons of water per gallon to phase separate a gasoline ethanol blend. This would be an incredibly large amount of water to be accidentally introduced into the system. To absorb this much moisture from the atmosphere (at a relative humidity of 70%) would take hundreds of days even if the gasoline cap was left off. Therefore, these concerns can be addressed simply by exercising caution that no water is introduced into the system, ensuring that the equipment has a gasoline tank cap that seals properly and filling the tank before extended storage periods (note that some manufacturers recommend draining of the fuel tank and system before storage).

All gasoline, whether conventional, oxygenated, or reformulated, deteriorates in storage. The gasoline "oxidizes" making it more prone to deposit formation. Because power equipment and recreational products are stored for extended periods, often six months or longer, manufacturers often make recommendations about storage.

A few recommend draining the fuel tank and fuel system. Many recommend treating the fuel with a fuel stabilizer which inhibits oxidation (i.e. anti-oxidant). Such products are available over the counter with one frequently recommended brand being STA-BIL. Some companies, including Briggs & Stratton, Toro/Lawnboy, and Yamaha sell a fuel stabilizer under their own brand name.

It is critically important that each manufacturer's storage recommendations be followed to the letter since gasoline is not usually of suitable stability for storage periods in excess of 60-90 days.

Over-Blending: Overblends of oxygenates in gasoline are rare and never intentional. Ethanol, MTBE, and other ethers all cost significantly more than gasoline. To overblend even 2% results in increased production costs exceeding 1¢ per gallon. Manufacturers of oxygenated gasolines are very cautious not to over-blend and most now use very sophisticated equipment to achieve precise blend levels at or below maximum permitted levels.

Manufacturers Positions

While one can debate test data versus myths and anecdotal reports of problems, consumers should focus primarily on what the equipment manufacturers recommend. They are, after all, most familiar with the quality of their products and whether or not they will operate satisfactorily on specific fuels.

Downstream Alternatives Inc. (DAI), in early 1994, compiled a data base of the manufacturers fuel recommendations. This includes a review of each company's current owner's manuals, and in some cases, supplemental technical service bulletins. The data base, which includes fuel and storage recommendations, is several pages long and too lengthy to include here. However Table 6-1 provides a recap of the manufacturers individual positions.

Not all manufacturers mention oxygenated fuel either as approved or not approved. Most of these manufacturers rely on the engine manufacturer's recommendation. If there are any doubts about a manufacturers position, it is recommended that the manufacturer or an authorized dealer be consulted. Among the listed manufacturers that specifically mention ethanol or MTBE, all permit these fuels to be used, although many offer special instructions.

A few manufacturers indicate they recommend non-blended fuels be used, but that oxygenated fuels are acceptable. Many manufacturers, especially of power equipment, offer special instructions for extended storage periods. A few manufacturers in the marine and recreational categories indicate that modifications may be necessary for proper operation on oxygenated fuels (e.g. TigerShark, Arctic Cat, Polaris).

Marine manufacturers tend to utilize the most negative wording regarding oxygenates. This may be due in part to their concerns about the potential for phase separation of alcohol blends in high moisture environments. Additionally, boats have a much longer useful life than some equipment and it is difficult to assess the impact of fuel components on boats that are 20-30 years old.

While the table provides an overview, consumers should consult their specific owners manual. If information is unclear or insufficient, an authorized dealer for the applicable brand of equipment should be consulted.

The fact that an individual manufacturer discourages the use of oxygenated fuels is not necessarily an indication that lower quality fuel system materials have been used. It may simply be an indication that the manufacturer has not conducted their own test program or may feel that they have insufficient field experience with these fuels.

Consumers should, however, be advised that if they are purchasing new equipment, they should ensure that the manufacturer permits the use of oxygenated fuels. Due to existing federal regulations, it is anticipated that 50% of all gasoline sold in the U.S. will contain oxygenates. No one wants to purchase a product that will operate satisfactorily on only half the available fuel supply.

The facts demonstrate that oxygenated fuels can be used in these applications provided the manufacturer's instructions are followed. Numerous tests and field demonstrations have proven the performance of oxygenated fuels in these applications.

In fact, the Portable Power Equipment Manufacturers Association (PPEMA), the trade association for sixteen manufacturers of gasoline powered hand held equipment such as chain saws, weed trimmers, and blower vacs conducted research on the use of reformulated gasoline in their products. In a March 7, 1995 press release, PPEMA noted "To date, this research program indicates there are no equipment problems with currently manufactured products …" PPEMA also conducted a survey of twenty-three state and regional power equipment dealer associations and found "…there have been no complaints concerning the performance of portable power equipment with new reformulated fuels."

Further, in a recent technical bulletin (Tech Exchange, February 1995), Yamaha Motor Corporation USA noted: "Extensive testing has been done on the effects of RFG on lubricity and materials compatibility, particularly with 2-stroke engines. Results show no adverse affects or catastrophic failures when using RFG. Tests also indicate that no increase in service intervals beyond the existing Yamaha recommendations were necessary."

Following Table 6-1 are excerpts from the fuel recommendations section of the equipment owner's manuals or applicable technical service bulletins for several manufacturers.

TABLE 6-1. - Summary of Power & Recreational Manufacturers' Positions on Oxygenated Fuel Use

The following recap is based on a review of each manufacturer's equipment owner's manuals. Wording may vary slightly across a manufacturers product line but is generally similar if not identical. Position and wording for a manufacturers two-stroke versus four-stroke models may vary. Also some manufacturers use several engine suppliers (e.g. Briggs & Stratton, Tecumseh, and Kohler) and may utilize the applicable engine manufacturer's fuel recommendations for models with those engines. Finally it should be noted that these recommendations are for new or late model equipment and may or may not apply to earlier models.

Manufacturer	Ethanol	MTBE
Power Equipment		
Am.Yard Prd/Roper/Rally	yes*	NM
Ariens	yes[1]	NM
Bolens/Troy-Bilt	yes*	yes
Briggs & Stratton	yes	yes
Coleman	yes*	NM
Cub Cadet	NM	NM
Dixon	yes	yes
Echo	yes	yes
Grasshopper	NM	NM
Homelite	yes	yes
Honda Power Eq.	yes	yes
John Deere (4 stroke)	yes	NM
Kawasaki	yes	yes
Kohler	yes	yes
Kubota	NM	NM
McColloch	yes*	yes*
MTD	yes	yes
Onan	yes*	yes*
Poulan/Weedeater	NM	NM
Ryobi	yes*	yes*
Sears	yes*	yes*
Shindaiwa	NM	NM
Simplicity	yes	NM
Snapper	NM	NM
Stihl Inc.	NM	NM
Tecumseh	yes*	yes*
Toro/Lawnboy	yes	yes

Manufacturer	Ethanol	MTBE
Motorcycle		
Harley Davidson	yes	yes
Honda	yes	yes
Kawasaki	yes	yes
Suzuki	yes*	yes
Yamaha	yes	NM
Recreational		
ArcticCat (Arctco)	yes*	yes*
Honda	yes	yes
Kawasaki	yes	yes
Polaris	yes*	yes*
SkiDoo/Bombardier	yes	NM
Suzuki	yes*	yes
Yamaha	yes	NM
Boats/Marine		
Honda	yes	yes
Kawasaki	yes	yes
Mercury	yes*	yes*
OMC (Johnson/Evinrude)	yes*	yes*
Pleasurecraft	yes*	yes
Tigershark (Arctco)	yes*	yes*
Tracker	yes*	NM
Yamaha	yes*	NM

Legend

yes = permitted/approved
yes* = indicates approved but may contain precautionary language or require modification
NM = not mentioned in owner's manual
[1] Engine manufacturer indicates approval but equipment manufacturer does not.

• Arctic Cat

GASOLINE-OIL

Recommended Gasoline

The recommended gasoline to use is 87 minimum octane regular unleaded. In many areas, oxygenates (either ethanol or MTBE) are added to the gasoline. Oxygenated gasolines containing up to 10% ethanol or up to 15% MTBE are acceptable gasolines; however, whenever using oxygenated gasolines, the carburetor main jet must be one size larger than the main jet required for regular unleaded gasoline. For example, if a 300 main jet is recommended for regular unleaded gasoline, a 310 main jet must be installed if using an oxygenated gasoline.

When using ethanol blended gasoline, it is not necessary to add a gasoline antifreeze since ethanol will prevent the accumulation of moisture in the fuel system.

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• Briggs & Stratton

Purchase fuel in quantity that can be used within 30 days to assure fuel freshness. We recommend the use of Briggs & Stratton Gasoline Additive. (See your Authorized Briggs & Stratton Service Dealer for Part No. 5041 or the single-use pouch.)

In countries other than U.S.A., leaded gasoline may be used if it is commercially available and unleaded is unavailable.

Note: Some fuels, called oxygenated or reformulated gasolines, are gasoline blended with alcohols or ethers. Excessive amounts of these blends can damage the fuel system or cause performance problems. Do not use gasoline which contains Methanol. If any undesirable operating symptoms occur, use gasoline with a lower percentage of alcohol or ether.

• Echo
(Power blowers S/N 186001 & up)

Use branded 89 octane R + M/2 unleaded gasoline or gasohol (maximum 10% ethyl alcohol, no methyl alcohol).

• Harley Davidson

- Gasolines containing METHYL TERTIARY BUTYL ETHER (MTBE): Gasoline/MTBE blends are a mixture of gasoline and as much as 15% MTBE. Gasoline/MTBE blends can be used in your motorcycle.
- ETHANOL (grain alcohol) is a mixture of 10% ethanol and 90% unleaded gasoline. It is identified as "gasohol". "ethanol enhanced", or "contains ethanol". Gasoline/ ethanol blends can be used in your motorcycle.
- REFORMULATED OR OXYGENATED GASOLINES (RFG): "Reformulated gasoline" is a term used to describe gasoline blends that are specifically designed to burn cleaner than other types of gasoline, leaving fewer "tailpipe" emissions. They are also formulated to evaporate less when you are filling your tank. Reformulated gasolines use additives to "oxygenate" the gas. Your motorcycle will run normally using this type of gas and Harley-Davidson recommends you use it when possible, as an aid to cleaner air in our environment.

• Honda

ETHANOL (ethyl or grain alcohol) 10% by Volume
You may use gasoline containing up to 10% ethanol by volume. Gasoline containing ethanol may be marketed under the name "Gasohol".

MTBE (Methyl Tertiary Butyl Ether) 15% by Volume
You may use gasoline containing up to 15% MTBE by volume.

• Kawasaki

Fuels Containing Oxygenates
Gasoline frequently contains oxygenates (alcohols and ethers) especially in areas of the U.S. and Canada which are required to sell such reformulated fuels as part of a strategy to reduce exhaust emissions.

The types and volume of fuel oxygenates approved for use in unleaded gasoline by the U.S. Environmental Protection Agency include a broad range of alcohols and ethers but only two components have seen any significant level of commercial use.

Gasoline/Alcohol Blends-Gasoline containing up to 10% ethanol (alcohol produced from agricultural products such as corn), also known as "gasohol" is approved for use.

Gasoline/Ether Blends-The most common ether is methyl tertiary butyl ether (MTBE). You may use gasoline containing up to 15% MTBE.

NOTE

Other oxygenates approved for use in unleaded gasoline include TAME (up to 16.7%) and ETBE (up to 17.2%). Fuel containing these oxygenates can also be used in your Kawasaki.

• Kohler Company

Gasoline/Alcohol blends
Gasohol (up to 10% ethyl alcohol, 90% unleaded gasoline by volume) is approved as a fuel for Kohler engines. Other gasoline/alcohol blends are not approved.

Gasoline/Ether blends
Methyl Tertiary Butyl Ether (MTBE) and unleaded gasoline blends (up to a maximum of 15% MTBE by volume) are approved as a fuel for Kohler engines. Other gasoline/ ether blends are not approved.

• Mercury Marine

Mercury Marine has issued bulletins on RFG and oxygenated fuels as follows:

Mercury Outboards/Mariner Outboards Service Bulletin No. 95-5 excerpts:

By controlling some "properties" of the fuel more closely, its toxic effects are reduced. This should be beneficial to outboard engines because it will be a cleaner burning fuel containing fewer deposit forming components. Vapor pressure and the evaporation rate at any given temperature of this fuel is closely controlled. This again should help engines because it will make the fuel more consistent.

The ethanol or the ethers used in these new reformulated gasolines are not something new. Both have been around several years. If you follow the information that has been put out into the field by Mercury Marine, other marine engine manufacturers and the automotive industry over the last few years concerning the use of fuels containing alcohol, problems should be kept at a minimum.

Mercury Marine Products
Mercury Marine products produced since 1980 are designed to be used with any commercially available regular grade lead free gasoline, including those containing oxygenates. The oxygenated fuels containing less energy cause the engine to run leaner. If for any reason an engine has been modified to lean out the fuel supply, or if the engine has not been tuned up recently there may be cause for concern. The results of running too lean can lead to detonation related problems or scuffed pistons.

ANY MAJOR BRAND OF UNLEADED (LEAD FREE) AUTOMOTIVE GASOLINE WITH A MINIMUM PUMP POSTED OCTANE RATING (R+M)/2 OF 87 IS SATISFACTORY FOR THESE OUTBOARDS. Outboards may use gasoline containing up to 10% ethanol, but the addition of a Quicksilver

Water Separating Fuel Filter* is recommended. Midgrade AUTOMOTIVE GASOLINE advertised to contain fuel injector cleaning agents is recommended for added internal engine cleanliness. Hi-Performance models-refer to the gasoline recommendations furnished with these engines.

1979 and older:
Additional inspection of the fuel system is required to detect and correct deterioration of elastomers and plastic parts (such as hoses, seals, and gaskets) caused by the alcohol and acids in the gasolines.
Refer to Mariner/Mercury Service Bulletin 93-3 for the complete USA and Canada fuel recommendations.

Note that similar guidance is given for Mercruiser models (Sterndrive/Inboards) in Mercruiser Service Bulletin No. 95-7.

• OMC

Use of alcohol extended fuels is acceptable **ONLY** if the alcohol content does not exceed:

- 10% ethanol by volume
- 5% methanol with 5% cosolvents by volume

In addition, OMC has issued guidance on reformulated gasoline in "Outboard Service Bulletin" No. 2289 (February 1995). In this bulletin OMC states the following:
Oxygenated fuels have been marketed for years. RFG is simply the latest generation. There are no new concerns or performance problems related to the use of RFG.

RFG does, however, have lower levels of volatile compounds and does contain oxygenates such as ether or ethanol. This formulation could create some or all of the situations normally associated with alcohol-extended fuel.

- Driveability - The increased level of oxygenates tends to make the engine run slightly leaner. Performance degradation or rough running might occur. All engines 1986 and newer, originally approved to run on unleaded fuel, will not require any modifications to run on RFG.

  NOTE Refer to OMC Service Bulletin No. 2155 for information about modifying engines 1985 and older.

- Materials Compatibility-RFG extended with alcohol could degrade rubber, plastic, or metal components of older fuel systems. RFG is compatible with all OMC original equipment fuel system components manufactured after 1985 and all OMC service replacement parts.

- Cold Starting - RFG is slightly less volatile and might cause hard starting.

- Phase Separation - RFG extended with alcohol will attract moisture from the atmosphere or from system contamination. Significant amounts of moisture will cause fuel/water phase separation.

- Fuel Economy - Engines running RFG might experience slightly lower fuel economy because of the higher level of oxygenates.

Be alert for these situations and be prepared to answer your customers' performance related questions.

• Suzuki

Gasoline Containing MTBE

Unleaded gasoline containing MTBE (Methyl Tertiary Butyl Ether) may be used in your motorcycle if the MTBE content is not greater than 15%. This oxygenated fuel does not contain alcohol.

Gasoline/Ethanol Blends

Blends of unleaded gasoline and ethanol (grain alcohol), also known as gasohol, may be used in your vehicle if the ethanol content is not greater than 10%.

• Tecumseh

All engines

Gasoline

Leaded gasoline, unleaded or leaded premium gasoline, gasohol containing no more than 10% ethanol, or unleaded gasoline containing no more than 15% MTBE (Methyl Tertiary Butyl Ether) can be used if unleaded regular gasoline is not available.

• Toro/Lawnboy

Use clean, fresh lead-free gasoline, including oxygenated or reformulated gasoline, with a octane rating of 85 or higher. To assure freshness, purchase only the quantity of gasoline that can be used in 30 days. Use of lead free gasoline results in fewer combustion chamber deposits and longer spark plug life. Use of premium grade fuel is not necessary or recommended.

IMPORTANT:
NEVER USE METHANOL, GASOLINE CONTAINING METHANOL. GASOLINE CONTAINING MORE THAN 10% ETHANOL OR GASOLINE CONTAINING MORE THAN 15% MTBE.

USE OF THESE FUELS CAN CAUSE ENGINE/FUEL SYSTEM DAMAGE.

Please note that the above are excerpts from fuel recommendations or applicable service bulletins and are meant simply to provide an overview. The entire fuel recommendation section of the owner's manual or applicable bulletins should be reviewed and followed in their entirety.

To obtain a complete copy of Downstream Alternatives Inc.'s Non-Automotive Gasoline Powered Equipment Manufacturers Fuel Recommendations data base, send your request along with US $3.00 (to cover copying and postage) to Downstream Alternatives Inc. • P.O. Box 2587 • South Bend, IN 46680-2587. Please include a self addressed mailing label.

Appendix A Fuel System Materials

A number of materials used in vehicle fuel systems have been tested for use with oxygenated fuel components as part of the process to secure EPA approval for their use. Post-1980 vehicle fuel systems typically utilize materials that are compatible with oxygenates and high aromatic gasolines. Pre-1980 and especially pre-1975 vehicle fuel systems may contain materials that are sensitive to high aromatic concentrations, ethers, or alcohols.

Table A-1 lists typical metals and the fuel system parts where they are likely to be used. The metals listed in this table were tested with ethanol blends and other alcohol-blended fuels by immersing metal coupons (1"x1" metal strips) in both the liquid fuel and the vapor phase of the fuel for 30 days at 110°F. Test results indicate that "overall, no oxygenated fuel/metal combination weight change (in 'dry' or 'wet' fuels) was significantly different from that observed for the base unleaded gasoline."

Table A-2 lists elastomers and non-metal materials along with their most typical use in the vehicle. These materials have also been tested in oxygenated fuel formulations. Results were generally comparable to that of gasoline not containing oxygenates.

Table A-1
Uses in Vehicles - Metals

Alloy	Typical Use
Aluminum alloy	Carburetor, accelerator pump, fuel pump casing
Magnesium alloy	Fuel pump casing, plate on steel, brass component specialty-purpose two-cycle engine, transmission housings
Copper	Brass and bronze
Zinc	Brass, air cleaner, carburetor
Carbon steel	Fuel line, fuel pump fittings and casings, fuel filter, fuel tank, carburetor fuel inlet, accelerator pump
Cartridge brass	Fuel line fittings, carburetor jets and inlet needle, fuel bowl float, power valve, valve seats
Aluminum bronze	Fuel pumps, fuel distribution system
Stainless steel	Carburetor fuel inlet needle, carburetor springs, catalytic converter, EGR valve
Aluminum alloy (cast)	Carburetor, accelerator pump, fuel pump casing, fuel tank fill pipe, intake manifold
Iron (cast)	Carburetor body, iron plates, engine block, intake and exhaust manifolds
Zinc alloy (cast)	Carburetor body, plate on steel, carburetor diaphragm
Terne plate	Fuel tank, fuel line, air cleaner assemblies

The materials listed in Table A-1 have been tested with various alcohol blends. There were no significant differences between the performance of the alcohol blends compared to a base unleaded gasoline.

Table A-2
Uses in Vehicles - Elastomers/Plastics

Materials	Typical Use
Nitrile	Carburetor gaskets, fuel cap gasket and seals, fuel filter tube grommet, gas hoses, fuel bowl float, accelerator pump diaphragms and plunger, fuel pump diaphragm
Viton®	EGR valves, fuel inlet needle tip
Neoprene® (Chloroprene)	Fuel tank vent to carburetor tube cover, gas hose cover
Epichlorohydrin	Diaphragm, carburetor choke control, fuel tube to filter, fuel vapor return tube, hoses
-Homopolymer	
-Copolymer	
Nylon 6 6	Carburetor float bowl baffle, fuel vapor storage canister, carburetor components
Delrin® (Acetyl polymer)	Carburetor components
Teflon®	Shaft coatings, venturi valve
Polyethylene (high density)	Hoses
Nitrophyl® (Nitrile rubber)	Floats, accelerator pump cups
Fluoroelastomers	Fuel line/hoses, carburetor needle tips, gaskets, O rings and fuel pump couplers, evaporative emissions line, fuel filler necks

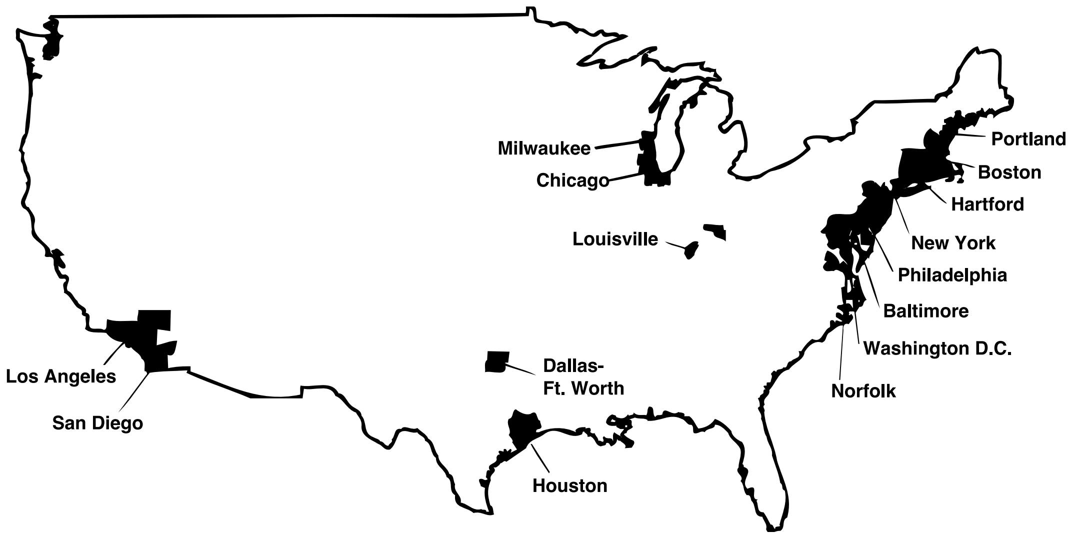
Note (1) Manufacturer data suggests that Viton® & flouroelastomers are the preferred materials for use with alcohols, ethers, and higher concentrations of aromatics.

Note (2) In some tests, parts composed of Epichlorohydrin have shown signs of deterioration when exposed to high concentrations of MTBE.

Appendix B Gasoline Program Areas

Figure B-1 Reformulated Gasoline Program Areas

The shaded portions of the map indicate areas that are required to use reformulated gasoline as of 1995.



Source: American Petroleum Institute

Table B-1 Oxygenated Fuel Program Areas

The metropolitan areas listed below required wintertime oxygenated fuel programs as of 1995. Several areas that originally required oxygenated fuel programs have either been or are in the process of being redesignated as CO attainment areas. Such areas include Baltimore, Boston, Hartford, Philadelphia, Washington DC, Greensboro, Syracuse, Cleveland, Duluth, and Memphis.

City	State(s)	City	State(s)
Albuquerque	NM	Chico	CA
El Paso	TX	Modesto	CA
Colorado Springs	CO	Reno	NV
Denver/Boulder	CO	Sacramento	CA
Ft. Collins	CO	San Francisco	CA
Missoula	MT	Stockton	CA
Provo/Orem	UT	Grant's Pass	OR
Anchorage	AK	Klamath Co.	OR
Portland/Vancouver	OR/WA	Medford	OR
Seattle	WA	Las Vegas	NV
San Diego	CA	Phoenix	AZ
New York City MSA	NY/NJ/CT	Los Angeles	CA
Fresno	CA	Spokane	WA
Minneapolis/St. Paul	MN		

Appendix C Glossary of Petroleum Terms

Additives: Chemicals added to gasoline in very small quantities to improve and maintain gasoline quality. Detergents and corrosion inhibitors are examples of gasoline additives.

American Society for Testing and Materials (ASTM): A non-profit organization that provides a management system to develop technical information in the published form. ASTM standards, test methods, specifications, etc. are written by those having expertise in specific areas. Current membership is over 28,000. ASTM specifications and procedures are recognized as definitive guidelines for gasoline quality as well as a broad range of other products.

Anti-dumping Rule: A provision of the 1990 Clean Air Act Amendments which restricts conventional gasolines (those not regulated under oxygenated fuel or reformulated gasoline programs) from resulting in any higher levels of emissions than gasoline sold in 1990.

Anti-icer: Typically an alcohol such as ethanol, isopropyl alcohol, or methanol. Added to gasoline in small amounts to eliminate trace levels of water thereby reducing the chance for fuel line freeze up.

Antiknock Index (AKI): Measures the ability of a gasoline to resist engine knock/ping. AKI is the average of Research and Motor Octane or (R+M)/2. Also commonly referred to as pump octane.

Anti-oxidant: A compound used to inhibit gum formation from oxidation of gasoline. A fuel stabilizer.

Aromatics: High octane blending components that have a benzene ring in their molecular structure. Commonly used term for the BTX group (benzene, toluene, xylene). Aromatics are hydrocarbons.

Benzene: Basic aromatic in the BTX group. Usually of higher value as a chemical feedstock. A known cancer causing agent.

British thermal unit (btu): One British thermal unit represents the amount of heat required to raise one pound of water one degree Fahrenheit (at sea level).

Butane: A light hydrocarbon used to raise octane and increase fuel volatility. Butane has a low boiling point and will vaporize quickly.

California Air Resources Board (CARB): A state regulatory agency charged with regulating the air quality in California. Air quality regulations established by CARB are often more restrictive than those set by the federal government.

Clean Air Act Amendments-1990 (CAAA-90): A series of amendments to the original Clean Air Act which includes requirements for oxygenated fuel programs in CO non-attainment areas and reformulated gasoline programs in certain ozone non-attainment areas.

Complex Model: A computer model that measures the effect of various fuel changes. The computer equations are based on test results from various test programs. Refiners will be required to use this model to develop their reformulated gasoline beginning in 1998, and may use it voluntarily prior to that date.

Component: A common term used to describe larger volume ingredients in gasoline.

Corrosion inhibitors: An additive used to reduce the corrosion properties of gasoline. Rust inhibitor.

Co-solvents: Heavier alcohols used with methanol to improve water tolerance and improve other negative characteristics of gasoline/methanol blends.

Deposit Control Additive: Performs same functions as detergent plus minimizes deposit buildup in intake manifold, intake ports, and underside of intake valves (dispersant).

Detergent: Additive used to prevent and/or clean up carburetor and fuel injector deposits.

Diolefins: An ingredient of gasoline which contributes to gum and lacquer formation in the fuel system and engine.

Distillation Curve: The reference to plotting a line connecting the percentages of gasoline that evaporate at various temperatures. Distillation curve is used as an important control for fuel standards such as volatility (vaporization).

Elastomer: The rubber like compounds used in fuel lines, evaporative canister lines, etc. Also used for other automotive applications such as brake lines and transmission lines.

Ethanol (ethyl alcohol, grain alcohol): Typically fermented from grain. An octane enhancer added at a rate of up to 10 percent in gasoline. Will increase octane 2.5 to 3.0 numbers at 10 percent concentration. Ethanol is a fuel oxygenate. Ethanol can also be used "neat" (pure) as a fuel in specially designed vehicles.

ETBE (ethyl tertiary butyl ether): An ether similar to MTBE. This fuel oxygenate is manufactured by reacting isobutylene with ethanol. The resulting ether is high octane and low volatility. ETBE can be added to gasoline up to a level of approximately 17%.

Fluidizer oils: Oils typically used with deposit control additives to control deposit formation on intake valves.

Gasohol: In the United States the term gasohol refers to gasoline which contains 10 percent ethanol. This term was used in the late 1970s and early 1980s but has been replaced by terms such as Super Unleaded Plus Ethanol or Unleaded Plus.

Isobutylene: A refinery process petrochemical that is reacted with methanol to form MTBE or with ethanol to form ETBE.

Lead (tetraethyl lead): An organo-metallic octane enhancer. One gram of lead increases the octane of one gallon of gasoline about six numbers. Lead will not be permitted in U.S. gasoline after 1995 (except for certain racing and aviation uses).

Light end hydrocarbons: Term used to denote hydrocarbons from crude distillation that are low density (lighter weight than gasoline) and have low boiling temperatures. Butanes are the most common light end hydrocarbon used in gasoline.

Metal deactivator: Gasoline additive used to neutralize the effect of copper compounds found in gasoline.

Methanol (methyl alcohol, wood alcohol): Typically manufactured from natural gas. In the 1980s methanol was used in combination with heavier cosolvent alcohols as an octane enhancer for addition to gasoline. Methanol is also being considered for use as a "neat" (pure) fuel in specially designed vehicles. Methanol is not typically blended into todays gasolines.

MTBE (methyl tertiary butyl ether): An ether manufactured by reacting methanol and isobutylene. The resulting ether is high octane and of low volatility. MTBE is a fuel oxygenate and is permitted in unleaded gasoline up to a level of 15%.

Octane: General term for a gasoline's ability to resist engine knock.
—*Pump Octane:* A term used to describe the octane as posted on the retail gasoline dispenser as (R+M)/2 and is the same as Antiknock Index.
—*Motor Octane:* The octane as tested in a single cylinder octane test engine at more severe operating conditions. Motor Octane Number affects high speed and part throttle knock and performance under load, passing, climbing hills, etc. Motor Octane is represented by the designation M in the (R+M)/2 equation and is the lower of the two numbers.
—*Research Octane:* The octane as tested in a single cylinder octane test engine operated under less severe operating conditions. Research Octane Number affects low to medium speed knock and engine run-on. Research Octane is represented by the designation R in the (R+M)/2 equation and is the higher of the two numbers.

Octane enhancer: Common term designating components that are added to gasoline to increase octane and reduce engine knock. Examples are toluene, ethanol, and MTBE.

Octane Number Requirement (ONR): The octane level required to provide knock-free operation in a given engine.

Octane Requirement Increase (ORI): The increase in octane requirement that results from the build up of combustion chamber deposits.

Olefins: A gasoline component resulting from several refining processes. Examples are ethylene, propylene, butylene. Olefins often contribute to the formation of gum and deposits in engines and the induction system.

Oxyfuels Mandate (Oxygenated Fuels Mandate): Common term used for regulatory program that requires the addition of oxygenates (alcohols or ethers) to fuels during certain months to reduce tailpipe emissions of carbon monoxide. Such programs are required by the 1990 Clean Air Act Amendments. In 1995 approximately 35 areas of the country used such programs.

Oxygenate: In the petroleum industry a term used to denote octane components containing hydrogen, carbon, and oxygen in their molecular structure. Includes ethers such as MTBE and alcohols such as ethanol and methanol.

Oxygenated Gasoline: Gasoline containing an oxygenate such as ethanol or MTBE. Provides chemical enleanment of the A/F charge thereby improving combustion and reducing tailpipe emissions of CO.

Ozone: Ozone (O_3) is formed when oxygen (O_2) and other compounds react in sunlight. In the upper atmosphere, ozone protects the earth from the sun's ultraviolet rays. Though beneficial in the upper atmosphere, at ground level, ozone is a respiratory irritant and considered a pollutant.

Reformulated Gasoline (RFG): Gasolines which have had their composition and/or characteristics altered to reduce vehicular emissions of pollutants. Specifically, those gasolines which meet the RFG requirements of the 1990 Clean Air Act Amendments.

Reid Vapor Pressure (RVP): A method of determining vapor pressure of gasoline and other petroleum products. Widely used in the petroleum industry as an indicator of the volatility (vaporization characteristics) of gasoline.

Simple Model: A specific gasoline formula developed by EPA for refiners to use in complying with the reformulated gasoline program. May be used in 1995, 1996, and 1997.

TAME (Tertiary Amyl Methyl Ether): An ether manufactured by reacting methanol with isoamylene. The resulting ether is high octane and of low volatility.

Toluene: An aromatic compound used to increase octane. The most common hydrocarbon purchased for use in increasing octane.

Toxics: As defined in the 1990 Clean Air Act Amendments, toxics include benzene, 1,3 butadiene, formaldehyde, acetaldehyde, and polycyclic organic matter.

Vapor Liquid Ratio: A measurement of the ratio of vapor to liquid at a given temperature used to help determine a gasoline's tendency to contribute to vapor lock in an automotive fuel system.

Volatility: Term used to describe a gasoline's tendency to change from liquid to vapor.

Volume Percent (v%): A percentage measurement based solely on volume without regard to differences in weight or density. For instance, a set of four blocks of identical size would each comprise 25 v% of the total volume. (Typically used to measure the concentration of alcohols and ethers in gasoline).

Weight Percent (wt.%): A percentage measurement based on weight. For instance a set of four blocks of equal size are each 25v% of the total volume. However, if block A, B, and C each weighed 1 pound and block D weighed 3 pounds, then block D would comprise 50 weight percent of the total weight while only comprising 25 volume % of the total volume. (Typically used to measure the oxygen content of gasoline).

Xylene: An aromatic compound which is a minor component of gasoline. Highly valued as a chemical feedstock (a hydrocarbon). Xylene is highly photochemically reactive and a major contributor to smog formation.

SAVE Reference Material

Changes in Gasoline III – Year 2000 Supplemental Update

Introduction

We have been receiving a lot of calls about when we plan on publishing a new "Changes in Gasoline" manual. The first version of the manual, printed in 1987, was updated and revised in 1988, 1990, and 1991. "Changes in Gasoline II," printed in 1992, was a complete rewrite as was "Changes in Gasoline III" in January 1996. These frequent updates were necessitated by such issues as the 1990 Clean Air Act Amendments, changes in fuel specifications, a need for information about oxygenated fuels and reformulated gasoline, and developing information about fuel system deposits.

Since 1996 changes to gasoline have been less frequent and there has been no need to update the manual since its contents continue to be accurate. There have, however, been some developments and more are on the horizon. At the end of 1999 refiners will implement Phase II of the reformulated gasoline program. A number of geographic areas have achieved compliance with carbon monoxide (CO) standards and are no longer required to use oxygenated fuels. The Governor of California has called for a phaseout and ban on the use of methyl tertiary butyl ether (MTBE) over concerns about groundwater contamination. The U.S. Environmental Protection Agency (EPA) has proposed a new set of rules called Tier II that would place more stringent requirements on automobiles while at the same time requiring a significant reduction in gasoline sulfur levels. There have also been some minor changes in ASTM gasoline specifications.

While these developments may not warrant a full rewrite of the "Changes in Gasoline" manual, we believe they do require some type of update for our hundreds of thousands of readers. Consequently we have developed this supplemental update to report on some of the aforementioned developments. This update is designed to be an insert to "Changes in Gasoline III." The information covered in each chapter of this supplement is designed to coincide with the same numbered chapter in the manual.

We continue to follow our approach of separating fact from fiction and presenting information on topics from a perspective most useful to the auto service technician. It is our hope that you will find this supplement a useful addition to your "Changes in Gasoline III" manual.

We would also like to express our thanks to the Renewable Fuels Foundation for their past sponsorship of the manual series and this supplemental update. Finally we would like to express our thanks to the service technicians, service shops, colleges, technical/trade schools, and auto manufacturer training programs that use our manual. Collectively they have allowed the "Changes in Gasoline" manual series to achieve a circulation in excess of a half million copies making our manual the most widely circulated gasoline reference manual used by the auto service and repair community.

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Chapter I Gasoline Quality – Standards, Specifications, & Additives – *Update*

Specifications & Standards

The American Society for Testing and Materials (ASTM) continues to be the guiding force in fuel standards. ASTM D 4814 continues to serve as the industry's voluntary consensus standard and is also adopted, in whole or in part, by several states as the legal guidelines for gasoline quality. Petroleum companies and pipeline operators continue to, in some cases, use specifications that are more stringent than the ASTM requirements. However, the ASTM guidelines are still the industry standard because they take into consideration the numerous requirements of both producers and users of fuel.

Octane Quality

This section of the manual remains accurate. However auto manufacturers are beginning to alter their guidelines for vehicle octane requirements at higher altitudes. Absent electronic controls, the octane requirement of a spark ignition engine is less at higher altitudes. The ASTM guidelines allow for lower octane gasoline at higher altitudes. As a result, gasoline marketers in higher altitude areas such as Denver have traditionally sold 85 octane (R+M)/2 gasoline as their regular unleaded compared to 87 octane at lower altitudes. Midgrade and premium grades in these markets are also usually two octane numbers lower than their counterparts sold at lower altitudes.

Some automakers have started specifying a minimum of 87 octane even at higher altitudes. This is because vehicle controls now compensate for changes in barometric pressure by adjusting spark timing and air/fuel mixture. Consequently the octane requirement of these vehicles remains approximately the same at various altitudes. As an example, Ford's 1999 model year owners manual states "We do not recommend gasoline labeled as 'regular' in high altitude areas that are sold with octane ratings of 86 or even less." A similar statement is used for vehicles requiring premium and specifies a minimum octane of 91.

Volatility

The volatility of gasoline continues to be an important factor in vehicle performance. The trend today is towards lower and lower volatility fuels to reduce evaporative emissions. While fuels of low volatility do reduce evaporative fuel emissions, they also vaporize less readily and in some cases may contribute to poor cold start/warm up performance especially in sensitive vehicles. Because of this a Driveability Index (DI) has been added to the ASTM specifications to help improve cold start and warm up performance. The DI is calculated with a formula that utilizes the temperature at which ten percent, fifty percent, and ninety percent of the fuel is evaporated.

Table S1-1 Driveability Index

$$DI = (1.5 \times T_{10}) + (3.0 \times T_{50}) + T_{90}$$

Where T_{10} = distillation temperature at 10% evaporated
Where T_{50} = distillation temperature at 50% evaporated
Where T_{90} = distillation temperature at 90% evaporated

Table S1-2 provides an example of the calculated DI using a volatility class E winter grade gasoline.

Table S1-2 DI Example

Winter fuel
T_{10} = 122
T_{50} = 190
T_{90} = 360

DI = (122 x 1.5) + (190 x 3) + 360
DI = 183 + 570 + 360
DI= 1113

In Table S1-2 we use a fuel with a T_{10} of 122˚F, a T_{50} of 190˚F, and a T_{90} of 360˚F. Applying the formula we see that the DI for this fuel is 1113.

The ASTM specifications specify a maximum DI for each volatility class. These are listed in Table S1-3.

Table S1-3 Driveability Index Maximum Based on Fahrenheit Scale

AA	=	1250
A	=	1250
B	=	1240
C	=	1230
D	=	1220
E	=	1200

The driveability index is a maximum. In other words, a number lower than that specified is acceptable but a higher number may cause poor cold start or poor warm up performance. This is why a lower maximum number is specified for winter grade gasolines.

The driveability index was developed a number of years ago. Consequently, a great deal of the development of the formula was on carbureted vehicles and utilized fuels which did not contain oxygenates. Recent testing has shown that the formula is also accurate for late model vehicles. However, it may become necessary to develop a small correction factor for oxygenated fuels. The DI formula continues to be assessed to determine if a more accurate formula can be developed.

It should be noted that while the automakers are concerned about fuels having the proper DI they have also expressed concerns about fuels that have T_{50} points that are too low. Where high DI fuels can contribute to poor cold start and warm up performance, if a fuel's T_{50} is excessively low it can vaporize too readily which can contribute to rich excursions making it difficult to maintain the air/fuel ratio at, or near, stoichiometry.

Gasoline Component Specifications

As mentioned in the manual, there are usually no ASTM specifications for individual gasoline components. However ethanol, and in some cases MTBE, may be blended at the terminal level. This has resulted in ASTM specifications being set for ethanol and MTBE. In the case of ethanol this continues to be ASTM D 4806. The Renewable Fuels Association (RFA) member companies continue to adhere to specifications that are more stringent than ASTM. These more stringent standards are set forth in RFA Publication #960501 and RFA Recommended Practice #930601 (which superceded RFA Recommended Practice #911201 listed in the manual). RFA member companies represent in excess of ninety-five percent of all fuel grade ethanol produced in the U.S. The manual also mentions development of an ASTM standard for MTBE and that standard has been completed. It is ASTM D 5893 Standard Specification for Methyl Tertiary Butyl Ether (MTBE) for Downstream Blending for Use in Automotive Spark-Ignition Engine Fuel.

Chapter 2 Changes in Gasoline Driven By Environmental Concerns – *Update*

Background

The auto manufacturers continue to do their part in reducing vehicle emissions. With the introduction of so-called Tier I vehicles in 1999 hydrocarbon (HC) emissions have been reduced by 98% compared to pre-control era vehicles. Likewise automotive emissions of oxides of nitrogen (NO_x) have been reduced 90% below pre-control levels. Despite these impressive gains, automobiles are still a significant source of air pollution because both the number of vehicles and the miles they are driven continue to increase. Consequently a number of strategies continue to be employed to try and achieve even greater reductions in the small amount of automotive emissions that remain. Future changes will include more stringent emissions standards on vehicles, further changes to gasoline and increasing numbers of alternative fuel vehicles.

Before moving on to some of the current and anticipated changes to gasoline, an update of topics covered in Chapter II of "Changes in Gasoline III" is in order. All key fuel related elements of the 1990 Clean Air Act Amendment have now been implemented with most now being in place for a number of years.

Oxygenated Gasoline Programs

When the oxygenated gasoline programs were introduced there were 36 areas designated as CO non-attainment areas. The oxygenated gasoline program proved effective in its very first year dramatically reducing the number of exceedences of the CO standard. In fact, today there are only 18 remaining areas that are required to use oxygenated gasoline because of their CO non-attainment status (See update of Appendix B for a complete listing of remaining areas.)

Reformulated Gasoline

While CO reduction is a success story, a number of metropolitan areas continue to exceed the standards for ozone. In fact, more areas, including Phoenix and St. Louis, have implemented reformulated gasoline programs since we last updated the manual in 1996. The Appendix B update includes a map of areas currently requiring reformulated gasoline.

There have also been a number of developments with the reformulated gasoline program, reformulated gasoline (RFG) itself, and the oxygenates it contains.

When Phase I of the RFG program was first implemented in 1995, refiners used EPA's Simple Model to achieve compliance. However beginning in 1998 refiners were required to use the Complex Model. This provided refiners with more flexibility in meeting RFG program requirements. However, Complex Model RFG continues to be very similar to the gasoline stipulated in the Simple Model. Its benzene level is still restricted to 1.0 volume % maximum and it must contain 2.0 weight % oxygen on average. Some refiners have made minor adjustments, lowering volatility, aromatic levels, and olefin content, as well as reducing sulfur levels. Adjustment of one or a combination of these items allow the refiner to manufacture complying RFG in a manner most efficient and cost effective for their refinery configuration and slate of products produced.

Starting in the year 2000, and barring any changes to existing law, industry will be required to sell Phase II RFG. As discussed in the next chapter the emissions reduction requirements for Phase II RFG are more stringent than Phase I.

California RFG

California implemented Phase II of their RFG program a number of years ago. There are some differences between the California RFG program (referred to as California Cleaner Burning Gasoline or CBG) and the federal program. We frequently receive questions on this topic since details on the differences were not covered in the manual.

The California CBG program is required statewide. The State of California uses their own computer model for compliance. This model, called the "California Predictive Model," is similar to the federal complex model but does not incorporate evaporative emissions.

California's CBG program attempts to achieve greater emissions reductions than the federal program by placing more stringent requirements on certain gasoline parameters. The California specifications place maximums on aromatic content (22%), olefin content (4%), and sulfur content (30 ppm). In addition the maximum distillation temperature for T_{50} and T_{90} are lowered.

California does not require the use of oxygenates in all its CBG. The federal RFG areas in California must contain the required 2.0 wt% oxygen content. These areas include the greater Los Angeles area, Sacramento, and San Diego. California CBG in the remainder of the state is not required to contain oxygen if it can be shown to meet the standard without it.

Perhaps the most significant development in California has been the governor's decision to ban the use of MTBE by December 31, 2002. This is discussed in more detail in the next chapter.

Also California has just started to consider plans for Phase 3 of their Cleaner Burning Gasoline Program although few details are yet available.

It is also worthwhile to note that vehicles certified to meet California's more stringent emissions requirement need California CBG to do so. This is in large part due to California CBG's lower sulfur level. Some northeast states now require vehicles meeting California emissions standards but these areas do not have low sulfur gasoline. Consequently California certified vehicles operating on higher sulfur fuels may illuminate the malfunction indicator light (MIL) or Check Engine Soon Light. The auto manufacturers have started including advisories on this in the fuel recommendation section of their vehicle owners manual. As examples, wording for the 1999 Chrysler and GM owners manuals are listed below.

- **Chrysler Corporation**
Sulfur in Gasoline
If you live in the northeast United States, your vehicle may have been designed to meet California low emission standards with clean burning, low sulfur, California gasoline. Gasoline sold outside California is permitted to have higher sulfur levels which may affect the performance of the vehicle's catalytic converter. This may cause the Check Engine or Service Engine Soon Light to illuminate.

Illumination of this light while operating on high sulfur gasoline does not necessarily mean your emission system control system is malfunctioning. Chrysler Corporation recommends that you try a different brand of unleaded gasoline having lower sulfur to determine if the problem is fuel related before returning your vehicle to an authorized dealer for service.

- **General Motors Corporation**
If your vehicle is certified to meet California Emission Standards (indicated on the underhood tune-up label), it is designed to operate on fuels that meet California specifications. If such fuels are not available in states adopting California emissions standards, your vehicle will operate satisfactorily on fuels meeting federal specifications, but emission control system performance may be affected. The malfunction indicator lamp on your instrument panel may turn on and/or your vehicle may fail a smog-check test. If this occurs, return to your authorized (GM) dealer for diagnosis to determine the cause of failure. In the event it is determined that the cause of the condition is the type of fuels used, repairs may not be covered by your warranty.

Other Information

Phase II of the Auto/Oil Air Quality Improvement Research Program (AQIRP) mentioned in the manual has been completed.

While the findings would be too voluminous to cover in accurate detail here, some of the findings were as follows:

- Lowering aromatics reduced HC, CO, and toxic exhaust emissions in current technology vehicles (Tier 0) and CO, NOx, and toxics in older technology vehicles.

- Adding oxygenates (from 2 to 2.7 wt%) reduced HC and CO in both current technology and older vehicles.
- Reducing olefin content reduced NOx in both current technology and older vehicles but increased HC emissions in both.
- Reducing vapor pressure by 1.0 psi (from 9 to 8) decreases HC, and CO exhaust emissions, and evaporative emissions in current technology vehicles.
- Reducing sulfur content from 450 ppm to 50 ppm gave the most significant and consistent exhaust emissions reductions lowering HC, CO, NOx, and toxics in current technology vehicles and Federal Tier I technology vehicles.

Other testing by various groups is always ongoing. This includes not only emissions research but driveability studies as well.

Chapter 3 Reformulated Gasoline, Oxygenates and Oxygenated Fuels – *Update*

Reformulated Gasoline-Phase II

The reformulated gasoline program has now been in place for five years confirming that there are no major performance related issues beyond the 2% to 3% fuel economy penalty.

Requirements for Phase II of the RFG program take effect on January 1, 2000 with refiners manufacturing compliant fuels well in advance of that date. Phase II of the program will require 25% reductions in volatile organic compounds (VOC), a 20% reduction in toxics, and a 5% reduction in oxides of nitrogen (NOx). These requirements are compared to Phase I requirements in Table S3-1.

Table S3-1 Reformulated Gasoline Requirements

	Phase I	Phase II
VOC reduction	15%	25%
Toxics reduction	15%	20%
NOx reduction	n/a	5%

With Phase II RFG available, the annual smog forming emissions reductions from the RFG program will be equivalent to removing 16 million vehicles from the road. Early indications are that refiners will meet the more stringent emissions reduction requirements of Phase II primarily through further lowering the vapor pressure of gasoline in summer months and reducing its sulfur content. Other minor modifications will likely include modest reductions in olefin and aromatic content and slight alteration of the distillation curve by removing some of the heaviest hydrocarbon components. Phase II gasoline will also be required to meet the same ASTM performance standards as Phase I so no major changes in performance are expected. In fact, EPA and industry recently completed a comprehensive test program utilizing Phase II RFG. The purpose of the test program was to identify any performance related issues with Phase II RFG before the fuel was introduced. EPA tested numerous vehicles in fleet operations over a period of several months. Climate conditions ranged from subfreezing temperatures in the north to record heat in the south. The combined test fleets drove over one million miles on Phase II RFG. Vehicles ranged in age from new to over 15 years old and included cars, trucks, vans, stepvans, and sport utility vehicles. The fleets involved and the number of vehicles operated on Phase II RFG are recapped in Table S3-2.

During the test program fuel system inspections were conducted. Driveability logs were also kept by vehicle operators to note any problems with starting, idling, etc. No problems with starting, running, idling, acceleration, or power were reported with any test fleet. One fleet manager described his fleet's use of Phase II RFG as "transparent." No increased or unscheduled repairs attributed to the fuel were reported.

In addition to the fleet tests, a separate study

Table S3-2: Fleet Vehicles in EPA's Phase II RFG Test

Fleet	Cars	Trucks
Boston Police Dept.	53	6
Elk Grove Village	37	12
Houston Lighting & Power	27	67

(Total vehicles operating on Phase II RFG does not include control vehicles)

was conducted on twelve vehicles of various makes, ages, and mileage. This study was to determine any differences in fuel economy between Phase I RFG and Phase II RFG. No significant differences in fuel economy between the two fuels was found.

It should also be noted that California has already implemented Phase II of its RFG program and extensive testing was also conducted prior to introduction of California Phase II CBG. These tests also included numerous automobile makes, models, and ages with varying odometer readings. Various non-automotive engines were also tested in the program. The final report did not indicate any areas of concern and, of course, this fuel has now been used in California for five years.

EPA also conducted tests on a variety of non-automotive engines. These tests included 177 pieces of lawn and garden power equipment, representing eleven use applications and utilizing both two stroke and four stroke engines ranging from 3 to 17 horsepower. Marine engines ranging from small two stroke 25 horsepower outboards to larger four stroke 500 horsepower inboards and stern drives were also tested. Finally, Harley Davidson conducted performance tests on six recent model motorcycles. This test also included system materials compatibility testing where various fuel system elastomers were soaked in Phase II RFG.

Based on the above EPA's final test report notes "…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." It is also worth noting that according to EPA survey data from last winter (1998/1999) "In virtually every RFG city, the fuel last winter met Phase II RFG Standards." This would indicate that few changes will occur as a result of the Phase II requirement.

Volatility: Since refiners now use the complex model there is not a set limit on gasoline vapor pressure. However in order to meet the emissions reduction requirements refiners still dramatically reduce the vapor pressure of summer grade gasolines. The summer grade of Phase II RFG will almost always have lower vapor pressure than the 7.2 to 8.1 psi required during the initial years of the program.

NOTE: In an effort to reduce vehicle emissions some areas have required gasolines with lowered vapor pressure during summer months. Such gasolines are not reformulated gasolines but merely use one of the control parameters used in RFG. The vapor pressure of such gasolines is typically as low or lower than the vapor pressure of RFG and may or may not contain oxygenates.

While low vapor pressure gasolines reduce evaporative emissions during the summer, they have little effect on exhaust emissions and may, in some cases, make exhaust emissions of some components increase. Likewise, the toxic emissions of these fuels are usually not as low as those from RFG. Finally, if vapor pressure is lowered too much, it can have a negative impact on cold start performance and warm up driveability.

Areas currently utilizing low vapor pressure gasolines include Birmingham, Alabama, Atlanta, Georgia, and El Paso, Texas. The St. Louis area had also been using this approach but switched to a RFG program in 1999. The Portland Maine area has recently switched from RFG to a low vapor pressure gasoline program.

Future Changes: With the RFG program fully implemented, the next change to gasoline looms on the horizon. EPA recently released a Notice of Proposed Rulemaking referred to as its "Tier II" rulemaking.

This program will require automobile manufacturers to further reduce vehicle emissions and would require a reduction in the sulfur content of all gasolines.

Currently gasoline contains an average of about 300 parts per million (ppm) sulfur. However the ASTM standards permit a sulfur content of up to 1000 ppm. Fuel quality surveys by the auto manufacturers have occasionally found gasolines with sulfur content near the upper limit or in a few cases, even above.

Sulfur poisons catalytic convertors reducing their effectiveness and shortening their life. In the past, sulfur contamination could be partially reversed through rich operation at high speed throttle positions. However, in order to meet current and future emissions standards, such operating modes are largely eliminated. Consequently gasoline with high sulfur levels can have a permanent negative impact on newer vehicles.

In order to assure that catalytic convertors remain effective, EPA has proposed limiting the sulfur content of gasoline to 30 ppm on average with no single gallon to exceed a maximum of 80 ppm. These requirements would be phased in beginning 2004 in order to provide refiners sufficient lead time to install the equipment necessary to reduce sulfur levels. The sulfur reduction requirements would apply to both reformulated and conventional gasolines. From a performance standpoint, sulfur reduction will be an improvement. Lower sulfur gasolines will lead to improved catalyst life and increased working effeciency.

Excessive sulfur levels in gasoline can also lead to acidic compounds in the crankcase oil which can contribute to premature engine wear. Potential problems of this nature would also be eliminated by the federal requirement for reduced sulfur levels.

As this supplemental update was being prepared, the Tier II rules had not yet been finalized but industry anticipates they will be adopted as proposed.

Oxygenates

MTBE: Methyl Tertiary Butyl Ether (MTBE) has been the most widely used oxygenate in the RFG program. It has been used in 75% to 80% of all RFG produced in the first five years of the program. The remaining RFG has contained ethanol. Initially there were complaints about the distinct odor of gasoline containing MTBE. Concerns were also expressed about the health effects resulting from exposure to MTBE. However research conducted thus far has failed to demonstrate that exposure to MTBE is of any greater concern than exposure to many other gasoline components or to gasoline itself. Some studies suggest that individuals with frequent exposure to MTBE vapors and/or exhaust emissions from gasoline/MTBE blends are more likely to have symptoms such as headaches, eye irritation, and nausea.

More recently, concerns have focused on the potential for MTBE to contaminate ground water and drinking water. In fact the Governor of California has acted to phase out and ban the use of MTBE in California gasoline. In California Executive Order D-5-99 the Governor stated that "On balance, there is significant risk to the environment from using MTBE in gasoline in California." The use of MTBE in California gasoline is to be phased down with a 100% removal to be achieved by December 31, 2002." While MTBE may be less harmful than other components in gasoline, it can contaminate ground water more quickly. When gasoline containing MTBE leaks from an underground tank (or is spilled) the MTBE tends to separate from the gasoline and moves farther and faster than other gasoline components. In some areas, MTBE has been detected in soil or water samples when no petroleum hydrocarbons were present. In fact, in its short history of increased usage, MTBE has become the second most widely detected contaminant in ground water samples. Other states have introduced legislation to ban the use of MTBE but to date only Iowa has done so. These developments make the future of MTBE's use in gasoline uncertain. While using MTBE in gasoline has provided satisfactory vehicle performance and helped clean up air pollution, the concern about ground water will likely lead to a reduction in the use of MTBE. Under current regulations if MTBE is banned refiners would need to use ethanol to meet the oxygen content requirement for RFG. Problems of this nature have not been experienced with ethanol.

Chapter 4 Fuel System Deposits Fuel Quality Testing – *Update*

The information contained in Chapter 4 of the manual is still current. We have received a number of inquiries about how to obtain the Specific Gravity Hydrometer.

The Specific Gravity Hydrometer test kit can be obtained from:

Engine Control Learning Center
892 Cambridge Drive
Elk Grove Village, IL 60007
Phone: 800-524-0944 or
847-228-0484

Chapter 5 Auto Manufacturer Fuel Recommendations – *Update*

The auto manufacturers fuel recommendations contained in "Changes in Gasoline III" were based on 1995 model year vehicle owners manuals. For the 1999 model year the recommendations regarding ethanol and MTBE remain largely the same. Four manufacturers, Ford, GM, Isuzu, and Rolls Royce have changed their recommendations regarding methanol indicating it is not approved for use. A few manufacturers have joined the ranks of those recommending RFG or detergent gasolines while a few have dropped their wording on detergent gasoline since all gasoline sold in the U.S. has been required to contain detergents for a number of years now. More manufacturers have also included language cautioning against the use of over-the-counter additives. In addition, Ford and GM have included a statement advising not to use premium gasoline in vehicles not specifically requiring it. Ford has also included wording advising against using gasoline below 87 octane at high altitudes (See chapter 1 Update - Octane Quality for additional discussion).

Eight manufacturers include wording advising against the use of methylcyopentadienyl manganese tricarbonyl (MMT). MMT is a metallic additive similar to lead. The auto manufacturers have expressed concerns that use of MMT will cause premature spark plug fouling, decrease catalytic converter efficiency and possibly cause the on-board diagnostic (OBD) system to malfunction.

Finally six manufacturers have included wording regarding sulfur content or related requirements. Vehicles designed for use in California (and certain Northeast states) have been designed to meet low emissions standards when operating on California RFG which is very low in sulfur. When these vehicles are operated on gasoline with higher sulfur levels, the emissions control system may not be able to function properly and the malfunction indicator light (MIL) (Service Engine Soon light) will illuminate.

This chapter includes a revised Table 5-1, now titled S5-1, to reflect these changes and additions. Information which is changed or new from Table 5-1 in the manual is indicated by bold type.

It should also be noted that ethanol flexible fuel vehicles (FFV) have now gone mainstream. Offerings include Fords FFV Taurus (by special order) and all 1999 and later model year Ford Rangers with the 3.0 L engine (as well as its Mazda twin). All 1998 and later model year Chrysler

Table S5-1
Auto Manufacturers' Fuel Recommendation Recap (based on 1999 model year owners manual)

Manufacturer	Approves of ethanol	Approved of MTBE	Approved methanol limits*	Precautionary language for oxygenates	Recommends or approves RFG	Recommends detergent gasoline	Precaution on use of after market additives	Advisory on sulfur content or California RFG	MMT Precaution	Octane advisory on altitude	Advisory on unnecessary premium use
Chrysler	yes	yes	no	x	yes	**x**	yes	**yes**	**yes**		**yes**
Ford	yes	yes	**no**	(1)	yes	**x**	(1)	**yes**		**yes**	**yes**
GM	yes	yes	**no**	x	yes	**x**	(1)	**yes**	**yes**		
BMW	yes	yes	3%	x	x	yes	x				
Honda/Acura	yes	yes	5%	x	x	**yes**	x		**yes**		
Hyundai	yes	yes	no	(1)	x	yes	x				
Isuzu	yes	x	**no**	(2)	**yes**	x	**(1)**	**yes**	**yes**		
Jaguar	yes	yes	3%	(1)	x	**yes**	x				
Kia	**yes**	**x**	**no**	**(1)**							
Mazda	yes	x	no	(1)	x	x	yes				
Mercedes Benz	yes	yes	3%	x	x	yes	yes				
Mitsubishi	yes	yes	no	x	yes	yes	x	**yes**	**yes**		
Nissan/Infiniti	yes	yes	5%	(1)	yes	x	yes				
Porsche	yes	yes	---	(1)	x	x	x				
Range Rover	yes	yes	**no**	x	yes	yes	**yes**		**yes**		
Rolls Royce	yes	yes	3%	x	x	x	**yes**		**yes**		
Saab	yes	yes	5%	x	yes	yes	x		**yes**		
Subaru	yes	yes	5%	x	yes	yes	x	**yes**			
Suzuki	yes	yes	5%	(1)	yes	x	x				
Toyota/Lexus	yes	yes	5%	(1)	x	yes	x				
Volkswagen/Audi	yes	yes	3%	(1)	x	yes	yes				
Volvo	yes	yes	no	x	x	**yes**	x				

* Requires equal amounts of cosolvents, plus corrosion inhibitors be used in the fuel.
(1) Mild precautionary wording (2) Strong precautionary wording
x No reference made in owners manual
Bold indicates change in information or additions of new information

product minivans (Chrysler/Dodge/Plymouth) with the 3.3L engine are also flexible fuel capable. Additionally GM has announced that for the 2000 model year certain configurations of its GMC Sonoma and Chevrolet S-10 pickup trucks will be flexible fuel capable. Consequently, there are hundreds of thousands of these vehicles on the road with hundreds of thousands more added to the fleet each year.

All of these vehicles are capable of operating on fuels containing up to 85% denatured ethanol (commonly referred to as E-85) or 100% gasoline or any mixture of the two.

As an example of the fuel recommendations for these vehicles we have included the fuel recommendation section from the 1999 Dodge Caravan FFV. Please note that Chrysler also recommends special engine oil while Ford does not.

1999 Dodge Caravan - E85 Recommendations

FLEXIBLE FUEL - (3.3L Federal Engines Only)

E-85 General Information

The information in this section is for Flexible Fuel vehicles only. These vehicles can be identified by the unique fuel filler door label that states Ethanol (E-85) or Unleaded Gasoline Only. This section only covers those subjects that are unique to these vehicles. Please refer to the other sections of this manual for information on features that are common between Flexible Fuel and gasoline only powered vehicles.

WARNING!

Only minivans with the E-85 fuel filler door label can operate on E-85.

Ethanol Fuel (E-85)

E-85 is a mixture of approximately 85% fuel ethanol and 15% unleaded gasoline.

WARNING!

Ethanol vapors are extremely flammable and could cause serious personal injury. Never have any smoking materials lit in or near the vehicle when removing the fuel filler tube cap (gas cap) or filling the tank. Do not use E-85 as a cleaning agent and never use it near an open flame.

Fuel Requirements

Your vehicle will operate on both unleaded gasoline with an octane rating of 87, or E-85 fuel, or any mixture of these two.

For best results, a refueling pattern that alternates between E-85 and unleaded gasoline should be avoided. When you do switch fuels, it is recommended that

- you do not switch when the fuel gauge indicates less than 1/4 full
- You do not add less than 5 gallons when refueling
- you operate the vehicle immediately after refueling for a period of at least 5 minutes

Observing these precautions will avoid possible hard starting and/or significant deterioration in driveability during warm up.

NOTE: When the ambient temperature is above 90˚F, you may experience hard starting and rough idle following start up even if the above recommendations are followed.

Selection of Engine Oil

For best performance and protection of your vehicle, use only crankcase engine oils that meet the following requirements:

- Engine Oil Selection for Operating on E-85 If you operate the vehicle on E-85 fuel either full or part-time, use only Mopar Flexible Fuel 5W-30 engine oil (P/N 4318086) or an equivalent that meets Chrysler Standard MS-9214. Equivalent commercial Flexible Fuel engine oils may be labeled as Flexible Fuel (FFV) or Alternate Fuel (AFV). These engine oils may be satisfactory if they meet the Chrysler Standard.

The 5W-30 engine oil installed at the factory meets the Chrysler requirements for Flexible Fuel engine oil.

SAE 5W-30 engine oil is preferred for use in Flexible Fuel engines.

Information on how to obtain a complete copy of the Auto Manufacturers Fuel Recommendations Data Base is included on page 27 of *Changes in Gasoline III*.

Chapter 6 Oxygenated and Reformulated Gasolines in Power and Recreational Equipment – *Update*

Downstream Alternatives Inc. is currently updating its "Non-Automotive Gasoline Powered Equipment Fuel Recommendations" data base and has also recently discussed fuel quality related issues with several manufacturers. The primary fuel related concerns of the manufacturers relate to enleanment and fuel storage considerations.

Enleanment: Most manufacturers indicate that oxygenated fuels can be used without adjustments. In fact, several that initially indicated that adjustments to the air/fuel ratio were necessary have since indicated that it is not necessary to make adjustments.

The issues related to enleanment are primarily hesitation/rough idle and concerns about engine temperatures which are discussed in the manual. It should be noted that while it is possible to change the air/fuel ratio on older equipment, newer equipment is subject to certain emissions standards and it is illegal to alter the settings on this newer equipment.

Storage Considerations: The deterioration of gasoline which is stored for extended periods continues to be an industry concern. Gasoline stored for extended periods begins to oxidize and weather. This can result is loss of octane, loss of volatile components that help with cold start, and most importantly can cause gum deposits in the carburetor. Most manufacturers continue to recommend that when equipment is stored for extended periods, the fuel should be treated with a stabilizer or the fuel system should be drained. The definition of extended storage varies among manufacturers. Additionally, some manufacturers offer slightly different guidelines for reformulated/ oxygenated gasolines than those for conventional gasoline.

Phase II RFG

As noted in Chapter 3, the RFG program requires implementation of Phase II RFG by January 1, 2000. Numerous and varied equipment has already been tested on Phase II RFG and no problems were found (see page 8 for additional details).

The fuel recommendations of equipment manufacturers have not changed significantly from the table in Chapter 6 of the manual. All major manufacturers continue to permit the use of ethanol and MTBE although some have switched to more positive wording in referencing them.

Information on how to obtain a current copy of our Non-automotive Gasoline Powered Equipment Data Base is included on page 32 of the manual.

Appendix B Gasoline Program Areas – *Update*

Figure SB-1 Reformulated Gasoline Program Areas

The shaded portions of the map indicate areas that are required to use reformulated gasoline as of 1999

NOTE: California RFG Program differs slightly from the federal program

Source: US EPA

Table SB-1 Oxygenated Fuel Program Areas

The metropolitan areas listed below required wintertime oxygenated fuel programs as of 1999. Over twenty areas that originally required oxygenated fuel programs have been redesignated as CO attainment areas and no longer require oxygenated fuel. Such areas include Baltimore, Boston, Hartford, Philadelphia, Washington D.C., Greensboro, Syracuse, Cleveland, Duluth, Memphis, and several cities in California.

City	State(s)	City	State(s)
El Paso	TX	Reno	NV
Colorado Springs	CO	Grant's Pass	OR
Denver/Boulder	CO	Klamath Co.	OR
Ft. Collins	CO	Medford	OR
Missoula	MT	Las Vegas	NV
Provo/Orem	UT	Phoenix	AZ
Anchorage	AK	Los Angeles	CA
Portland/Vancouver	OR/WA	Spokane	WA
Minneapolis/St. Paul (1)	MN		

(1) The State of Minnesota has implemented a statewide oxygenated fuels program

Source: US EPA

The "Changes in Gasoline" manual and supplement are no longer available in hard copy. Single copies are available via the internet at www.ethanolrfa.org. This web site also contains information for multiple copy purchase.

Changes in Gasoline III was prepared specifically to provide information about gasoline and gasoline quality to automotive service professionals, instructors, and automotive students, as well as the small engine service technician. It is based on over 170 references and was reviewed by a technical panel to ensure technical accuracy. In addition, an advisory board provided input to help focus the manual on issues of key interest to the auto service/repair industry.

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