

Changes in GASOLINE IV

SAVE!
Important
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Material

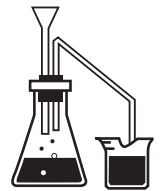
The Auto Technician's Guide to Spark Ignition Engine Fuel Quality



**Completely updated for 2009.
Contains the latest
information on gasoline
quality issues
and E85!**



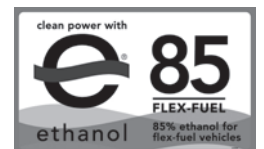
 RFF RENEWABLE
FUELS
FOUNDATION



Fuel Specifications
and How They
Affect Vehicle
Performance



Changes in
Fuels Due to
Government
Regulations



New Information
on E85 and
Flex-Fuel
Vehicles



“Changes in Gasoline IV” is the 2009 edition of the ongoing series of “Changes in Gasoline” manuals. The first manual, “Changes in Gasoline & the Automobile Service Technician,” was originally published in 1987. Since that time the multiple editions of the manual have collectively exceeded a circulation of 500,000 copies. The numerous editions of the manual have been necessary due to changes in federal regulations, fuel specifications, and advances in automotive technology. For instance, “Changes in Gasoline” was written shortly after the elimination of lead from gasoline, while “Changes in Gasoline II” was written after passage of the 1990 Clean Air Act Amendments. Most of the requirements of the 1990 Clean Air Act Amendments were implemented by 1995, resulting in the publication of “Changes in Gasoline III.”

In 2005, the federal government passed the 2005 Energy Policy Act (EPACT05). This legislation did away with requirements that reformulated gasolines contain oxygen. It also included a requirement that an increasing amount of our transportation fuel be from renewable sources such as ethanol. In 2007 the federal government passed the Energy Independence and Security Act, further increasing the renewable fuels requirement. As such, the transportation fuel landscape is poised for another series of changes. There are, of course, other important developments with transportation fuels, most notably, fluctuating prices. This, too, has reignited the interest in renewable fuels. These developments make it apparent that it is again time to update the “Changes in Gasoline” manual.

In this version of the manual we continue our tradition of presenting information about fuel 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 on Flex-Fuel Vehicles (FFVs) and E85 has been added, as E85 appears to be emerging as the renewable fuel of choice.

We encourage you to read on and see why over a half million readers, mostly 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 IV

The Auto Technician's Guide to Spark-Ignition Engine Fuel Quality

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 initially focused on the automobile and have resulted in automotive technology which significantly reduces vehicle emissions compared to pre-control levels.

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.

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 fall of 1992, over thirty-five areas of the nation failing to meet the federal standard for carbon monoxide (CO) were required to implement oxygenated fuel programs.

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.

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.

Today we are undergoing another round of changes in fuels. Petroleum companies have ceased using Methyl Tertiary Butyl Ether (MTBE) in the U.S. due to concerns about groundwater contamination. Congress has eliminated the oxygenate requirement for reformulated gasoline and also passed legislation requiring increased use of renewable fuels to reduce our dependence on foreign oil. When *Changes in Gasoline* was last completely rewritten in 1996, gasoline ethanol blends represented less than 10% of the gasoline sold. Today the level is close to 70%.

Government regulations focus on the environmental impact of gasoline and reducing foreign imports by increasing the use of domestically produced renewable fuels. But 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 ASTM International (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.

As the technology of both fuels and vehicles continue to advance, the efforts to constantly improve the relationship between an engine and the fuel that powers it becomes even more important.

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. This information was once 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, ethanol, and reformulated gasoline are discussed in detail, as is E85. 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 including a chapter on Flex-Fuel vehicles and E85.

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 by an educational grant from the Renewable Fuels Foundation, a nonprofit 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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Chapter 1 Gasoline Quality - Standards, Specifications, and Additives

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 should 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 and environmental regulations 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 ASTM International (ASTM). ASTM specifications are established by consensus based on the broad experience and close cooperation of producers of gasoline, producers of ethanol, 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) as

determined by the formula $(R+M)/2$. 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.

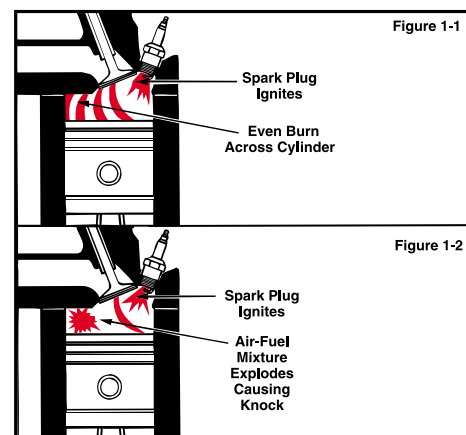
In general, the RON affects low to medium speed knock and engine run-on or dieseling. If the Research Octane Number is too low, the driver could experience low speed knock and engine run-on after the engine is shut off.

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, and is, in fact, currently being studied again because some smaller displacement engines that are prevalent today respond to octane differently.

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.

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**

<u>Design/Operating Factors</u>	<u>In Use Conditions</u>
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	

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 significant 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 severe 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 require-

ment 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.

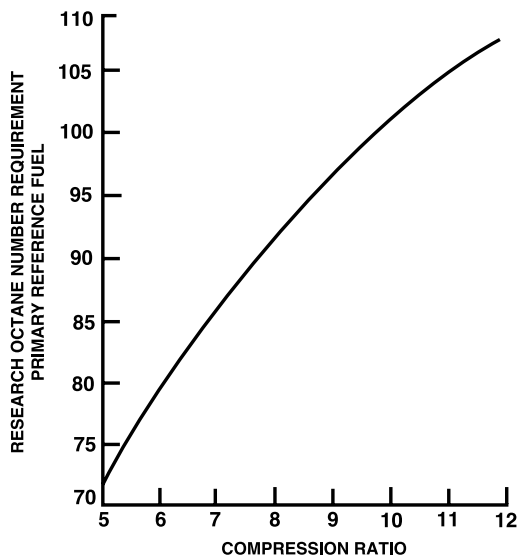
Many of the variables related to octane and octane requirement can be totally or partially compensated for by the engine control systems in most late model vehicles. For instance, vehicles equipped with knock sensor devices allow the engine control system to advance or retard the ignition timing in response to engine knock. Many 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 largely offset. For this reason the octane number specified in the owners manual should be used even though lower octane gasoline may be available at high altitude locations.

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

**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.

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.

Volatility

Gasoline is metered in liquid form, through the fuel injectors (or in older vehicles, carburetors), 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

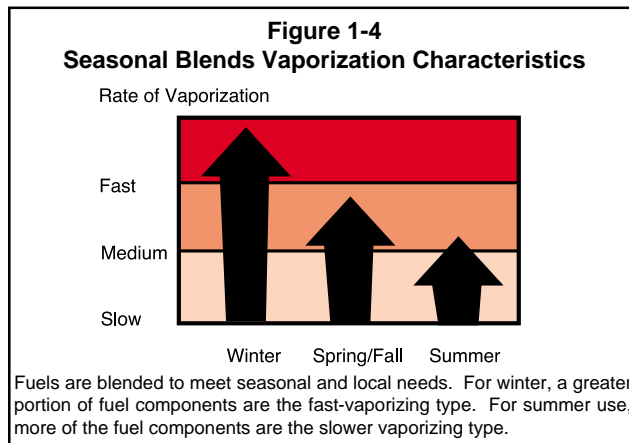
Volatility Too Low	Volatility Too High
Poor cold start	High evaporative emissions/ Canister overload & purge
Poor warm up performance	Hot driveability problems/ vapor lock
Poor cool weather driveability	Fuel economy may deteriorate
Increased deposits -crankcase -combustion chamber -spark plugs	
Unequal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

and has an effect on the areas listed in Table 1-2.

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.

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.

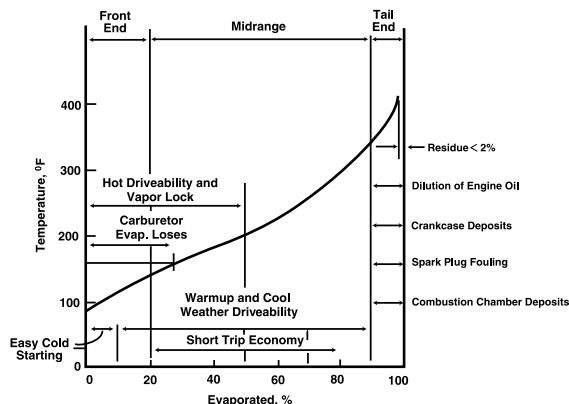
There are four parameters used to control volatility limits, vapor pressure, distillation, vapor liquid ratio, and driveability index. ASTM provides standards for the test procedures to measure or calculate these characteristics. There are six vapor pressure/distillation classes of gasoline designated AA, A, B, C, D, and E. AA is the least volatile while E is the most volatile. The AA volatility class was added to reflect the 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 helps in rating 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 is sometimes used 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 have become more popular, the term RVP is usually 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.

**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.

However it is important to note that it is one of only four 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 at lower temperatures. If the front end volatility is too high, it could cause hot restart problems. If it is too low, cold start and warm up performance may suffer.

The distillation test is used to determine fuel volatility across the entire boiling range of gasoline. Gasoline consists of a variety of mostly hydrocarbon 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.

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 affects short trip fuel 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, ten percent 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 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 volatility classes and six vapor lock protection 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 (v%) to 10 v% 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. Reformulated gasoline has requirements that may necessitate even lower vapor pressure during the EPA volatility control season.

Note that the vapor lock protection class and corresponding TV/L20 are not by volatility class. Thus fuels of

**Table 1-3
ASTM D 4814 GASOLINE VOLATILITY REQUIREMENTS**

Vapor Pressure/ Distillation Class	Distillation Temperatures ° F			End Point Max.	Vapor Pressure psi/Max.	Driveability Index Max' F	Vapor Lock Protection Class	Temp. for Vapor-Liquid Ratio of 20 °F/Min.
	10% Evap. Max.	50% Evap.	90% Evap. Max.					
AA	158	170-250	374	437	7.8	1250	1	140
A	158	170-250	374	437	9.0	1250	2	133
B	149	170-245	374	437	10.0	1240	3	124
C	140	170-240	365	437	11.5	1230	4	116
D	131	170-235 h	365	437	13.5	1220	5	105
E	122	170-230 h	365	437	15.0	1200	6	95

ASTM D 4814 specifies volatility requirements and a 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.

ASTM footnote h - Gasolines known from the origin to retail that will not be blended with ethanol may meet a minimum 50% evaporated distillation temperature of 66°C (150°F) for volatility classes D and E only. Gasolines meeting these limits are not suitable for blending with ethanol.

different volatility classes may be in the same vapor lock protection class.

The volatility of gasoline continues to be an important factor in vehicle performance. The trend today is toward lower and lower volatility fuels to reduce evaporative emissions. While fuels of low volatility do reduce evaporative 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. This formula is listed in Table 1-4

Table 1-4 Driveability Index Formula
$DI = (1.5 \times T_{10}) + (3.0 \times T_{50}) + T_{90} + (2.4^\circ F \times V\% \text{ ethanol})$
Where T_{10} = distillation temperature at 10% evaporated Where T_{50} = distillation temperature at 50% evaporated Where T_{90} = distillation temperature at 90% evaporated Where V % = volume percent ethanol

In Table 1-5 we use a fuel with a T_{10} of 122°F, a T_{50} of 190°F, a T_{90} of 360°F, and 10v% ethanol. Applying the formula, we see that the DI for this fuel is 1137. ASTM D 4814 specifies a maximum DI for each volatility class.

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.

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 (engine management system over-adjusts to a rich setting) making it difficult to maintain the air/fuel ratio at, or near, stoichiometry.

Table 1-5 DI Example	
Winter fuel	
$T_{10} =$	122
$T_{50} =$	190
$T_{90} =$	360
V% ethanol =	10
DI =	$(1.5 \times 122) + (3 \times 190) + 360 + (2.4 \times 10)$
DI =	183 + 570 + 360 + 24
DI =	1137

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 1-6 lists the various specifications and their importance. A copper strip corrosion standard ensures that the fuel will not create excessive corrosion in the vehicle fuel system. Stability standards are

Table 1-6 Gasoline Specifications and Their Importance	
<u>Specification</u>	<u>Importance</u>
<u>Antiknock Index (AKI)</u> Research Octane Number (RON) Motor Octane Number (MON)	Low to medium speed knock and run-on High speed knock/Part-throttle knock
<u>Fuel Volatility</u> Vapor Liquid (V/L) Ratio Distillation Vapor Pressure (VP) Driveability Index	Vapor lock Cool weather driveability, hot start and hot driveability, vapor lock, evaporative losses, crankcase deposits, combustion chamber and spark plug deposits Low temperature starting, evaporative losses, vapor lock Cold start/warm up performance
<u>Copper Corrosivity</u>	Fuel system corrosion
<u>Silver Corrosivity</u>	Fuel system corrosion of silver/silver alloy
<u>Stability</u> Existent Gum Oxidation Stability	Induction system deposits, filter clogging Storage life-increased oxidation reduces storage life
<u>Sulfur Content</u>	Exhaust emissions, engine deposits and engine wear
<u>Metallic Additives (lead and others)</u>	Catalyst & oxygen sensor deterioration (unleaded vehicles)

controls of a fuel's tendency to contribute to induction system deposits and filter clogging as well as determining the fuel's storage life.

Sulfur content is limited by federal regulations to ensure proper catalyst operation and life. There is a specification for the maximum lead and metallic additive content in unleaded fuel because lead can foul catalysts. The Clean Air Act Amendments of 1990 prohibited the sale of leaded gasoline after December 31, 1995 except for certain aviation and racing applications.

Recently a Silver Strip Corrosion specification was added to the ASTM standard. This was added to protect silver and silver alloy fuel system components, such as in-tank sending units, from aggressive types of sulfur contaminants.

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 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 notable exception is ethanol. Ethanol is manufactured outside of the refinery, and is added to the gasoline by the fuel manufacturer or blender. 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 ethanol content 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 #960501).

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 blended in very small quantities. As an example, 100 pounds of deposit control additive may treat as much as 20,000 gallons of gasoline.

**Table 1-7
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

Many of these additives are also available in diluted form as over-the-counter products for consumer addition. Table 1-7 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 rates of addition, these additives may enhance fuel quality.

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 the EPA regulations. As of December 31, 1995 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.

It is worth mentioning that most auto manufacturers recommend against the use of over-the-counter gasoline additives in most cases. Some do recommend the use of detergent/deposit control additives to keep fuel injectors and intake valve deposits under control. Another exception is when a vehicle or gasoline powered equipment is stored for extended periods (3 months or more). In this case a fuel stabilizer (anti-oxidant) such as STA-BIL will help reduce formation of gum and peroxides. Never exceed the recommended treat rate because to do so does not improve results and could contribute to deposits.

Chapter 2 Changes in Gasoline Driven by Environmental Concerns and Energy Security Issues

Background

Over the past four 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 throttle body fuel injection and then port fuel injection, became a dinosaur in less than a decade.

Many vehicle manufacturers started utilizing engines with three or four valves per cylinder in an effort to improve fuel economy, reduce emissions, increase engine power, and permit engine down-sizing while maintaining performance. While these modifications resulted in an increasingly complex vehicle, they have achieved significant reductions in vehicle emissions. By the mid 1990s exhaust emissions of carbon monoxide (CO) and hydrocarbons (HC) had been reduced by 96% while nitrogen oxide (NO_x) emissions had been reduced by 76% compared to the emissions of pre-control era vehicles.

Until 2004, new vehicles were certified to what were referred to as U.S.E.P.A. Tier 1 Standards. Beginning in 2004, Tier 2 Standards came into effect. In the Tier 1 Standard, an emission limit applied to each vehicle. For Tier 2, passenger cars and light duty trucks are divided into ten BINS. BINS 9 and 10 were interim BINS used for 2004 through 2007. Most new vehicles at present (2009) are Tier 2 BIN 5. The graph in Figure 2-1 shows the current eight passenger car BINS. California sets its own standards. Other states have the right to apply the California requirements. Many states such as Maine, Massachusetts, and New York have done so. These standards are similar to, but more restrictive than, the federal standards and are also depicted in Figure 2-1.

As Figure 2-1 demonstrates, emission limits continue to be reduced. In fact tailpipe emissions have been reduced to such low levels that new measurement equipment needed to be developed to measure such low levels.

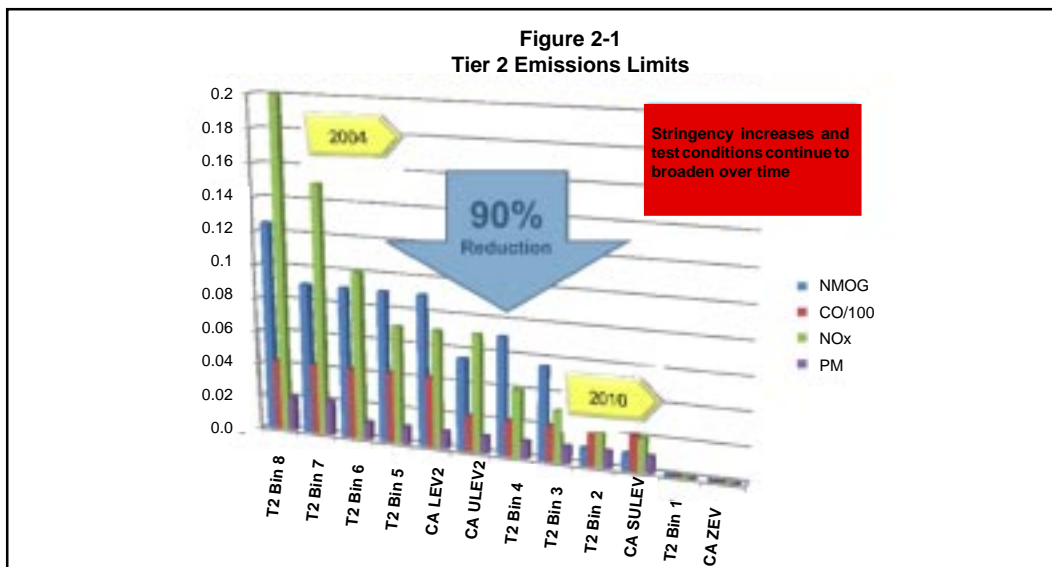
Engineers are anticipating standards even more stringent than Tier 2 BIN 5 and are already working on technology solutions. This will be focused on downsized turbocharged engines with direct fuel injection as well as advanced combustion strategies, GM has already introduced new direct injection (DI) engines in the Cadillac CTS and Chevy Malibu for the 2009 model year. DI engine sales were 585,000 units for the 2009 model year and are estimated to reach 5.1 million units by 2014. Cleaning up emissions within the cylinder is almost always less expensive than using other strategies. All of this effort will be occurring at the same time that automakers are trying to achieve the new higher fuel economy standards. Improved fuel economy not only reduces the need to import oil but it also greatly reduces emissions of CO₂, a greenhouse gas.

Much 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 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. In the recent past, changes were 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.

**Figure 2-1
Tier 2 Emissions Limits**



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 was 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 20v% in the 1970s to approximately 32v% in the 1990s with many gasolines exceeding a 40v% 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 increased volatility 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 the 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 the 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, the EPA implemented Phase II of their volatility control levels, which required 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, the EPA will permit gasoline/ethanol blends (containing 9v% to 10v% 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 nearly eliminated fuel related hot driveability problems in all but the most sensitive of vehicles.

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

1990 Clean Air Act Amendments

In November 1990, the President 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 program 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 their EPA designated baseline fuel. The major gasoline related provisions of the 1990 Clean Air Act Amendments are recapped in Table 2-1.

**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.

Nearly all areas of the country are now in attainment. See Appendix A for areas of the nation that are currently required to use reformulated gasoline as well as those using so called "boutique fuels".

Conventional Gasoline: Conventional gasoline represents all gasoline sold in non-control areas or in other words, all gasoline that is not reformulated gasoline. 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 (NO_x), carbon monoxide (CO), and toxic air pollutants (TAP) when compared to their baseline gasoline (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. More recently the EPA has lowered the permitted level of sulfur in gasoline to an average of 30 ppm per gallon and a maximum cap of no more than 80 ppm per gallon to protect advanced emission control

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

Compared to their EPA designated baseline average, each refiner's gasoline cannot result in higher emissions of the following:

Volatile organic compounds	(VOC)
Oxides of Nitrogen	(NO _x)
Carbon monoxide	(CO)
Toxic air pollutants	(TAP)
Benzene	
1,3 Butadiene	
Polycyclic organic matter	
Acetaldehyde	
Formaldehyde	

devices in current vehicles.

Conventional gasoline may, and usually does, contain ethanol. Ethanol content is limited to a maximum of 10v%. Conventional gasoline continues to be subject to ASTM performance standards as covered in Chapter 1.

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 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 have dealt 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 has been determined to be 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.

There were various phases to the reformulated gasoline program including a Phase 1 Simple Model and a requirement that RFG contain oxygenates such as ethanol or MTBE. There is no longer a requirement for RFG to contain an oxygenate. However almost all RFG contains ethanol because it helps refiners achieve the compliance standards. Since 1998 the EPA has regulated RFG through the use of the "Complex Model".

The standards require a reduction of 25% for volatile organic compounds (VOCs), 20% for toxics, and 5% for oxides of nitrogen (NOx).

California implemented its own version of the 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.

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. This model was updated in 2008.

California's CBG program attempts to achieve greater emissions reductions than the federal program by placing more stringent requirements on certain gasoline parameters.

The EPA 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 EPA is currently working to update the Complex Model to be more reflective of today's vehicle population.

The model developed from these tests enable the prediction of emissions reductions (or increases) that result from various changes to a 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 in 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.

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

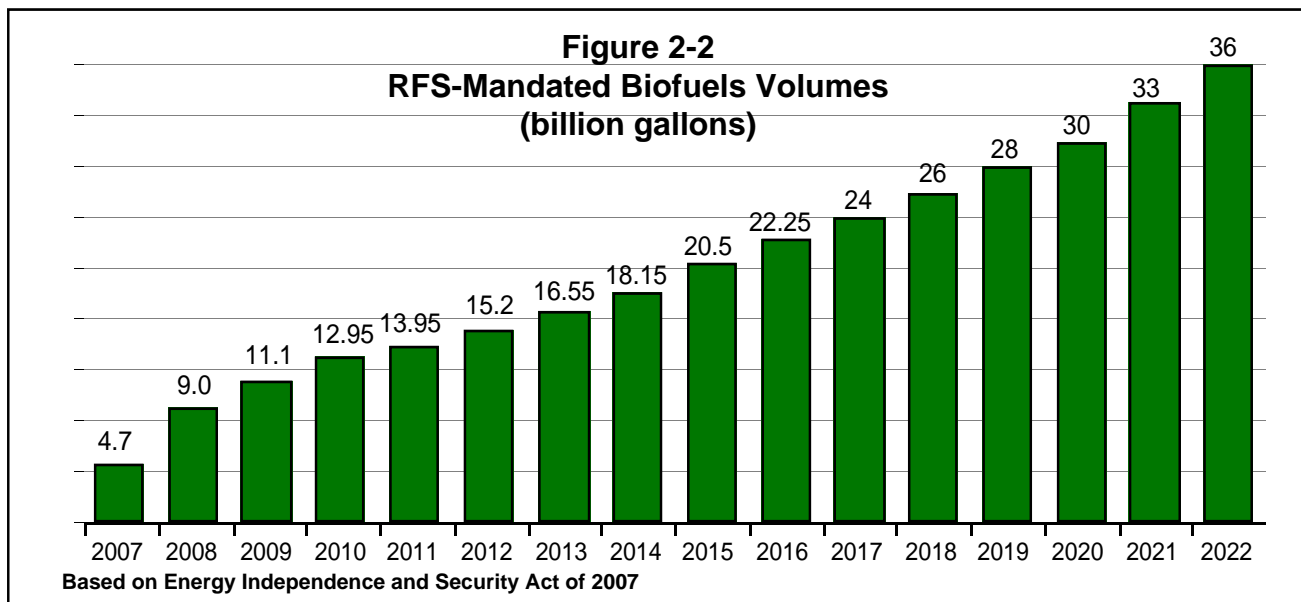
Detergent Requirements: The 1990 Clean Air Act Amendments also required, beginning in 1995, that all gasolines be treated with detergents and deposit control additives to minimize deposits in carburetors, fuel injectors, and on intake valves. Fuel intake system deposits are an environmental issue because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

Environmental considerations have been the driving force for changes in transportation fuels in the past and will no doubt continue to influence public policy. While efforts to lower vehicle emissions will continue, much of the focus in the future will be on reducing Greenhouse Gas (GHG) emissions and their impact on climate change.

Boutique Fuels: Some states have chosen to set environmental requirements for gasoline sold in certain areas within their state. These fuel requirements typically specify some, but not all, of the requirements of reformulated gasoline. Most often this includes reduced vapor pressure. Since these fuels are unique to a certain area, and slightly different from both reformulated and conventional gasolines, they are often called "boutique fuels". Areas with such requirements are identified on the map in Appendix A.

Energy Security Issues

Recently public policy efforts have been directed at reducing our dependence on foreign oil. In 2007, the United States imported 60% of its crude oil and petroleum products at great expense to the nation's trade deficit. In 2005, recognizing that such dependence is detrimental to U.S. interests, Congress passed, and the President signed, the Energy Policy Act of 2005 (EPACT2005). This legislation included the nation's first Renewable Fuels Standard (RFS). The requirement would have increased the use of renewable fuels (such as ethanol and



biodiesel) to 4.0 billion gallons per year in 2006 escalating to 7.5 billion gallons in 2012. Then in late 2007, the Energy Independence and Security Act (EISA) was passed by Congress and signed by the President. Among this legislation's numerous renewable fuel provisions was a much more aggressive RFS. The EISA requires the use of 4.7 billion gallons of renewable fuel use in 2007 increasing to 36 billion gallons per year in 2022. The mandated biofuels use by year is depicted in Figure 2-2.

The majority of the requirements will be met through the use of ethanol. It is anticipated that 15 billion gallons per year of ethanol will be made from corn with another 20 billion gallons from other feedstocks such as agricultural waste, wood waste,

and energy crops such as switch grass. However, from the auto technician's viewpoint, the source is unimportant - ethanol is ethanol - regardless of the feedstock.

In 2008, over 9 billion gallons of ethanol were used. In fact over 60% of all gasoline sold in the U.S. in 2008 contained ethanol. Ethanol blends are no longer a niche fuel but have become the standard fuel in the U.S.

The market for E10, the typical gasoline ethanol blend containing 10v% ethanol, requires about 14 billion gallons per year. In order to meet the RFS requirement it will require the use of products such as E85 in Flex-Fuel Vehicles (see Chapter 5) or else blend levels higher than 10v% in existing vehicles. Research on the use of higher blend levels is currently being conducted.

NOTES

Chapter 3 Gasoline Formulations and Ethanol

Background

The last version of this manual provided extensive detail about reformulated gasoline (RFG) and the oxygenates they contained at the time. These included Methyl Tertiary Butyl Ether (MTBE) and ethanol. At present, about 20 states have banned the use of MTBE because of concerns about groundwater contamination and the petroleum industry has basically ceased using it in their gasoline anywhere in the United States. As mentioned in the previous chapter, there is no longer a requirement that RFG contain an oxygenate, although most refiners utilize ethanol in the production of their fuels to meet the RFG regulations. Ethanol is also widely used in conventional gasoline and 70% of all gasoline sold in the U.S. in late 2008 contained ethanol. So, in fact what is sold as gasoline today is not technically gasoline because gasoline is comprised of hydrocarbons whereas ethanol is hydrogen, carbon, and oxygen. The correct terminology would really be "spark ignition engine fuel" but the term gasoline is still commonly used.

In the 1990s, oxygenated fuels were required in carbon monoxide non-attainment areas. These programs were so successful that all but one area achieved compliance soon after adopting these programs. Here too, though the requirement has ended, these areas continue to sell gasoline ethanol blends.

With a few exceptions, those areas where RFG is not required utilize conventional gasoline (usually containing ethanol) which also has to meet certain EPA requirements. Finally, some states have adopted their own regulations to reduce gasoline related emissions in certain areas. These fuel requirements typically adopt certain, but not all, the requirements of RFG, such as lower vapor pressure or reduced sulfur. Because these fuels are unique to a specific market, the government and petroleum industry refer to them as "boutique fuels".

As noted earlier, a map showing the geographic areas where various fuel types are sold is included in Appendix A.

Regardless of the type of fuels used in given markets for environmental reasons, it is still necessary that they meet the requirements set forth in ASTM D 4814 as discussed in Chapter 1.

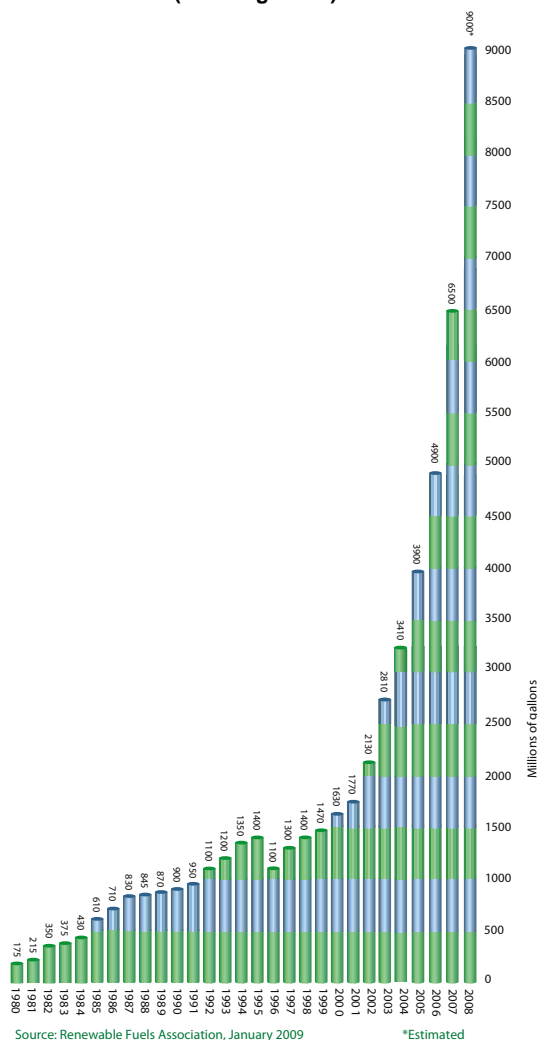
Ethanol

Perhaps one of the most often misunderstood fuel components in gasoline is ethanol. Ethanol's use as a fuel is not new. Henry Ford designed Ford's earliest model vehicles to operate on ethanol or gasoline. But the modern fuel ethanol industry began in the late 1970s.

Figure 3-1 shows the growth of ethanol production from 1980 through 2008. In those 28 years, production increased from a mere 175 million gallons to an estimated 9 billion gallons in 2008.

In the U.S., most ethanol is currently produced by the fermentation of the starch in corn. Research to produce ethanol from cellulosic materials such as agricultural wastes,

Figure 3-1
Historical U.S. Ethanol Production
(million gallons)



waste wood, and energy crops such as switch grass in ongoing. Pilot plants have already been constructed and a few commercial scale plants are under construction. Several announcements have been made proposing additional plants.

Because ethanol is produced from plant products it results in a net reduction in greenhouse gas (GHG) emissions because the plants used as feedstock to produce it absorb carbon dioxide (CO₂) from the atmosphere during their growth. As a result, using ethanol in transportation fuels not only reduces oil use but also GHG emissions.

As recently as 1990, only 10% of the nation's gasoline contained ethanol. By the end of 2008 approximately 70% of the nation's gasoline contained ethanol and is expected to approach 100% by 2011 or 2012.

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 ethanol began to see more widespread use and therefore these problems were often attributed to 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, the 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 lower than 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.

Also higher fuel pressures and other improvements in fuel systems have resulted in vehicles that are much less sensitive to fuel volatility.

Materials Compatibility: Auto manufacturers have, for many years, used materials that are compatible with ethanol. However, with ethanol's now widespread use, certain myths have resurfaced, so they warrant discussion here. In earlier technical papers this topic was covered in greater detail, including photographs and results from various tests. This information can be segmented into two broad 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 added to gasoline to protect their plain steel pipe. Therefore, corrosion inhibitors have been routinely added to gasoline for many years.

Ethanol is more soluble in water than gasoline. 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 vehicles 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.

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 decades ago.

Although the addition of ethanol to gasoline causes swelling in nitrile rubber fuel hoses, swelling is relatively insignificant with ethanol blends in modern vehicles. 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 with high aromatic levels may cause greater swelling than either fuel component by itself.

Automobile and parts manufacturers have been responsive to the changes occurring in 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 ethanol and higher aromatic gasolines. 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 10v% ethanol blends, their upgrading of fuel systems occurred at different times. In general, 1980 and later model years should not experience problems with 10v% ethanol blends. 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 and ethanol. 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 B.

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

For several years the standard fuel in Brazil has been a blend of 22-25v% ethanol in gasoline. Brazil has older vehicles that operate on straight ethanol. Nearly all new car sales are Flex-Fuel Vehicles (Brazilian Flex-Fuel Vehicles differ somewhat from models sold in the U.S. which are discussed in Chapter 5). Their ethanol program has been in operation for decades. The materials compatibility problems have been overcome and have assisted in identifying more suitable fuel system materials.

Numerous tests have indicated that materials compatibility on E10 blends 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 or equipment, deposits in fuel tanks and fuel lines were dissolved 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 3-2).

Fuel System Deposits: Numerous tests have shown that

Figure 3-2
Excerpts from Purolator Products - Service Bulletin (5-1-80)

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.

proper additive treatment effectively controls the deposit tendencies of gasolines including those containing oxygenates. The 1990 Clean Air Act Amendments require (as of 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) E10 blends contain approximately 3.5 w% oxygen. 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 (rough idle, engine stalls). 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) Today's vehicles, and most cars and trucks produced since the late 1980s, 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 engine management system (the range within which the engine management system and input devices can properly measure and compensate for).

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 gasoline blend containing 10v% ethanol would require almost 4 teaspoons of water before phase separation would occur. Therefore in routine operations, ethanol is more likely to suspend moisture and carry it out of the fuel system than hydrocarbon only 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. The lower phase of the sample with water will appear to be cloudy. 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 all federal, state, and local regulations.

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

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 116,000 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 116,000 btu/gallons. So the energy content, and therefore the fuel economy, can

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%

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.

The lower energy content of winter fuels and the other

Table 3-3
Gasoline Energy Content
Conventional Gasoline - btu Content

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

Difference between summer maximum and winter minimum 7.26%

wintertime influences on fuel economy can easily lead to reductions of 10-20% in miles per gallon during the coldest winter months.

The original oxygenated fuel programs, being winter-time only programs, were therefore incorrectly blamed for significant fuel economy losses when in fact numerous other variables also contributed to fuel economy losses during winter months.

As an example, denatured ethanol contains 77,300 btu per gallon. A 10v% ethanol blend would contain about 3.2% less energy per gallon. However, in controlled tests the fuel economy loss has been far less than would be indicated by the 3.2% lower energy content.

Table 3-4
Energy Content of E10 Blends
(when blended with 114,000 btu/gallon base fuel)

	Energy content (btu/gal)	
Ethanol	77,300	
Gasoline	114,000	
E10 blend	110,300	3.2% reduction

Table 3-4 lists the btu/gallon (energy content) of denatured ethanol, a typical gasoline, and an E10 blend.

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 E10 blends. This is because the chemical enleanment from the oxygen results in more complete combustion of the fuel, which partially or totally compensates for the slightly lower btu value.

In many cases refiners often alter the base fuel to which ethanol is added, resulting in the gallon having approximately the same btu content as the original all hydrocarbon gallon.

Higher Ratio Ethanol Blends

In the U.S. gasoline ethanol blends containing more than 10v% ethanol are not permitted for sale except for use in Flex-Fuel Vehicles (see Chapter 5). However, as this edition of *"Changes in Gasoline"* was being written, government and industry were engaged in extensive research to determine if higher levels of ethanol could be permitted in existing non-Flex-Fuel Vehicles, the so-called "legacy fleet". Blends containing 15v% to 20v% were being tested in various technology vehicles. Such tests include materials compatibility, exhaust and evaporative emissions, and durability including the catalytic converter. Driveability tests and other work has also been undertaken. This is being done because the use of higher blend levels in the existing fleet would help meet the Renewable Fuels Standards that currently exist.

Before the EPA would approve of a higher ethanol blend level it will be necessary to demonstrate that such levels would not cause the failure of emissions control devices over their useful life. For modern vehicles this represents 120,000 to 150,000 miles. The testing to make such a demonstration could take 24 months or perhaps longer. Even if such demonstration is made, additional testing will be needed to determine the impact higher blend levels would have on small non-road engines (SNRE). This category includes numerous recreational, lawn and garden, and construction/industrial engines. Engines include single and twin cylinders, of both 4 stroke and 2 stroke design of various displacements, applications, and duty cycles. Also much of this equipment is low cost and designed for a short useful life, in some cases less than 100 hours. Many also have fixed air/fuel ratios and are non-computerized. Since higher blend levels would contain more oxygen there are concerns about additional enleanment

which might increase engine head temperatures. Also much of this category of equipment is used in very close proximity to its operator so any safety issues will also need to be researched.

It is quite likely that slightly higher levels of ethanol will be permitted in gasoline. However it is not yet clear when that

may occur or what the permitted level would be.

Following is a quick reference guide of facts about ethanol.

Quick Reference Guide to Facts About Ethanol

Q: What is ethanol?

A: Ethanol is the same alcohol used in alcoholic beverages but near 200 proof. Water is removed so it is suitable for blending to gasoline and a small amount of denaturant is added so that it cannot be consumed.

Q: Why is ethanol added to gasoline?

A: There are many reasons. Refiners often choose to add ethanol because it is clean burning and increases octane. More recently, federal regulations require refiners to use increasing amounts of ethanol to help reduce energy imports thereby reducing America's dependence on foreign oil.

Q: Is there a difference between today's gasoline ethanol blends and gasohol?

A: The term gasohol used in the early 1980s also applied to 10v% ethanol blends. Today, such blends are commonly called E10 and held to rigorous ASTM specifications that did not exist in the earlier gasohol era.

Q: How does ethanol provide environmental benefits?

A: The oxygen present in ethanol improves combustion thereby lowering CO emissions. Ethanol also reduces emissions of air toxics compared to other gasoline components. Finally, because the feedstocks for ethanol are agricultural and biomass crops, they reduce direct greenhouse gas emissions because the feedstocks absorb CO₂ during their growing cycle. The extent of this reduction depends on the type of feedstock, the ground it is grown on, and numerous other factors.

Q: What do the auto manufacturers say about ethanol? Do they approve of using it in their vehicles?

A: All auto manufacturers approve of the use of up to 10v% ethanol in their U.S. vehicles. 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.

Q: How does ethanol affect fuel system deposits?

A: Today all gasolines, including those containing ethanol, must meet the same fuel system cleanliness standards implemented by the EPA in 1995. Therefore, all gasolines are treated with the type and volume of additive necessary to provide acceptable fuel system cleanliness under normal operating conditions.

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 ethanol affects driveability?

A: Yes, there have been a number of tests and fleet studies on the effect of ethanol on vehicle driveability. These studies have generally indicated that the average consumer will detect no difference in vehicle performance. You should not experience any driveability problems on properly formulated gasoline/ethanol blends.

Q: If ethanol is an acceptable fuel component, why do some auto technicians believe it deteriorates 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 has 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 technician. This results in a perception that the major difference in today's gasolines is ethanol content when, in fact, many other changes have also taken place.

Q: Have any tests been performed to determine the compatibility of ethanol with fuel system parts?

A: Yes, several tests have been performed which indicate that blends containing up to 10v% ethanol are compatible with the metals and elastomers in modern vehicle fuel systems.

Q: Will ethanol result in reduced fuel economy?

A: The addition of ethanol will usually result in a fuel economy loss of about 2-3%. This has been confirmed through numerous tests (See Chapter 3, pages 17 & 18).

Q: Does ethanol 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 ethanol, is controlled by the EPA volatility regulations. Con-

sequently, hot driveability problems related to fuel volatility have been largely eliminated. (See Chapter 1, pages 5-7 and Chapter 3, page 16).

Q: What about using gasoline ethanol blends in power equipment and other small engine applications?

A: Nearly every mainstream manufacturer has indicated that ethanol blended fuels containing up to 10v% ethanol 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).

Q. I see blends like E85 and E30. Can I use these higher blends in my vehicle?

A. These fuels are for use in Flex-Fuel Vehicles (FFVs) only. They are not a legal fuel for use in non-FFVs. See chapter 5 for a discussion on FFVs and how to determine if a specific make and model is an FFV or not.

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 10v% ethanol will only increase fuel vapor pressure by 0.5 to 1.0 psi, methanol addition at levels as low as 3v% or 4v% can increase fuel vapor pressure by 2.5 to 3.0 psi.

Chapter 4 Fuel System Deposits Fuel Quality Testing

Fuel System Deposits

Another fuel quality issue receiving 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), causes 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 all 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 gasoline ethanol blends and reformulated gasolines as well as conventional gasoline.

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 the EPA.

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

It appears these regulations have solved many, but not all, deposit problems. 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% on any individual injector, will result in some occurrence of the problems mentioned above, particularly in

**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

sensitive vehicles.

There has been a great deal of debate about the causes of injector 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. Some fuel injectors have been shown to be more prone to deposit formation. In these injectors, the fuel injector flow-control is manufactured to very exacting tolerances. The metering orifice opening is approximately 0.002".

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 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.

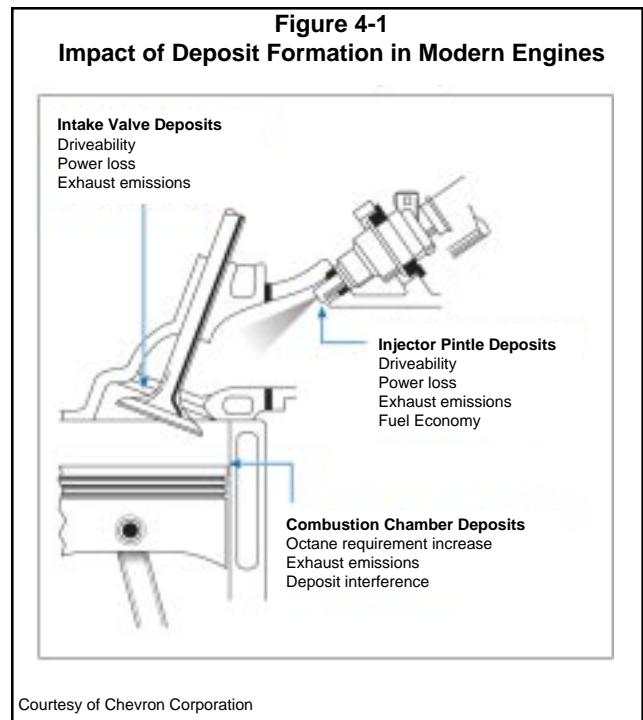
Of course, today, the issue of "sufficient quantities of appropriate detergents" is addressed through the EPA regulations. In addition the automakers and their original equipment manufacturers (OEMs) have redesigned injectors that are less prone to deposit formation. As an example GM introduced the "Multec" 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 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, in 1991 GM advised their service network that some aerosol 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) although generally the use of in-tank additives such as those previously mentioned is permitted.

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 over-treatment 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 as well



as combustion chamber deposits (CCD) and their consequences. The symptoms of IVD are often difficult 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 can result 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.

Valve deposits have, of course, always been present in

**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

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).

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 the 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 gasoline ethanol blends and reformulated gasolines although the proper treat rate may vary compared to non-blended 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 the industry to constantly improve its additive packages.

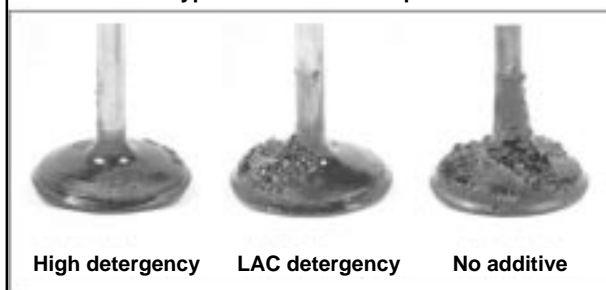
While the EPA regulations require that today's gaso-

lines be properly treated to minimize IVD, technicians may encounter some vehicles driven on repetitive short cycle trips that may still develop deposits that cannot be adequately controlled by additives.

The EPA detergent regulations only require what is called the LOWEST ADDITIVE CONCENTRATION (LAC), the lowest treat rate for which the additive has been shown to minimize deposits. This is sometimes called the "Keep Clean" rate. Moreover, the tests are performed on a representative test cycle that may not be as severe as some driving patterns and conditions.

The "Keep Clean" rate may be insufficient for vehicles driven on repetitive short cycles or those that are frequently in the "hot soak" mode (e.g., taxis, delivery vehicles, law enforcement). Such vehicles benefit from the higher detergent "Clean Up" rate. A comparison of deposits for no additive, the LAC treat rate, and high detergency can be seen in Figure 4-2.

**Figure 4-2
Typical Intake Valve Deposits**



Courtesy of Chevron Corporation

Because of this, in 2004 some of the auto manufacturers (GM, BMW, Honda, and Toyota) established a program called "Top Tier Detergent Gasolines". This is a voluntary program where petroleum companies can submit data to the auto manufacturers to have their gasolines designated and listed as Top Tier. Testing uses the more rigorous CARB limits for IVD and CCD and an industry valve sticking test. The petroleum marketer must certify that all grades sold meet the Top Tier criteria. A list of the Top Tier detergent gasolines as well as additional information can be found on the sponsoring auto manufacturers' websites.

Once deposits reach levels that degrade vehicle operation, corrective action is required. 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, in the past, indicated that "...General Motors laboratory tests have shown that injector cleaners have little or no effect on intake valve deposits."

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 espe-

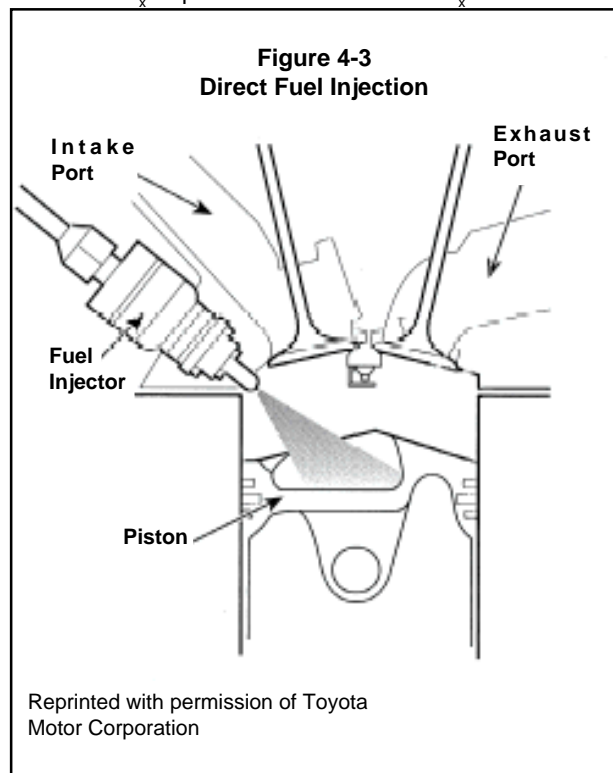
cially those who drive predominantly short driving cycles, may wish to consider using such after-market additives. One after-market additive frequently recommended is Chevron's Techron®. Additives employing chemistry similar to Techron® are also available from many of the auto manufacturers through their 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.

Direct Injection: As noted earlier, auto manufacturers are beginning a significant shift to Direct Fuel Injection. Engines employing this technology are referred to as Direct Injection Spark Ignition (DISI) engines. The direct injection system necessitates much higher fuel pressures to overcome in-cylinder pressure and the injectors are exposed to more heat and combustion products than port fuel injectors (see Figure 4-3). Functioning in this harsher environment may lead to increased deposits. However, with only a short time in the market, field experience is insufficient to determine if deposit profiles may change.

Most direct injection systems employ a combination of *homogenous* and *stratified charge*. The homogenous charge mode is used for wide open throttle and heavy accelerations. Injection during the intake stroke provides a near stoichiometric mixture.

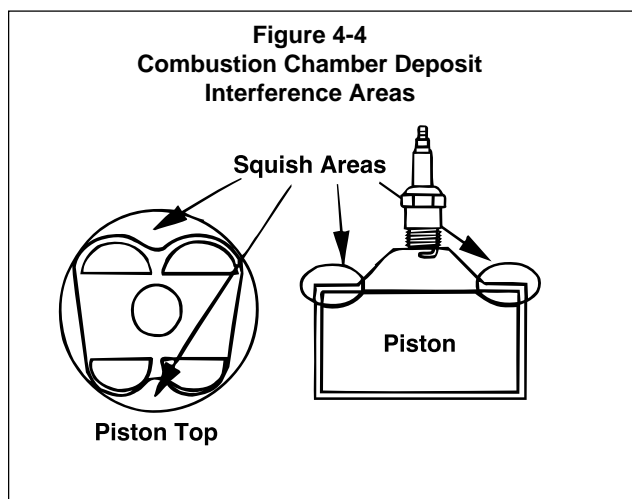
For less severe operation, such as cruising, a stratified charge is more ideal. In this mode a lean fuel mixture is concentrated around the spark plug, which results in improved thermal efficiency. This results in lower fuel consumption and therefore CO₂ emissions compared to a port fuel injected system. Lean fuel conditions can, however, increase NO_x emissions. In some systems, this may necessitate use of a lean NO_x trap to achieve ultra-low NO_x emission stan-



dards. Consequently lean burn modes are not used as frequently in the most recent DI engines.

Combustion Chamber Deposits: Additive development has led to chemistries which control PFI deposits and IVD with some now minimizing combustion chamber deposits (CCD).

CCD has been shown to increase the octane requirement of an engine. In the mid 1990s, another problem called Combustion Chamber Deposit Interference (CCDI) was 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" (sometimes called carbon rap) type of noise when the deposits on the piston squish area build up and cause contact with deposits on the cylinder head (see Figure 4-4).



As with other deposits, there are a number of variables and contributing factors involved in assessing CCD formation. 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.

CCDI was a problem with some mid 1990s models. The auto manufacturers resolved this problem in later models by increasing squish height and/or design modifications.

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 375 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.

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 4-5)

The graph in Figure 4-6 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.

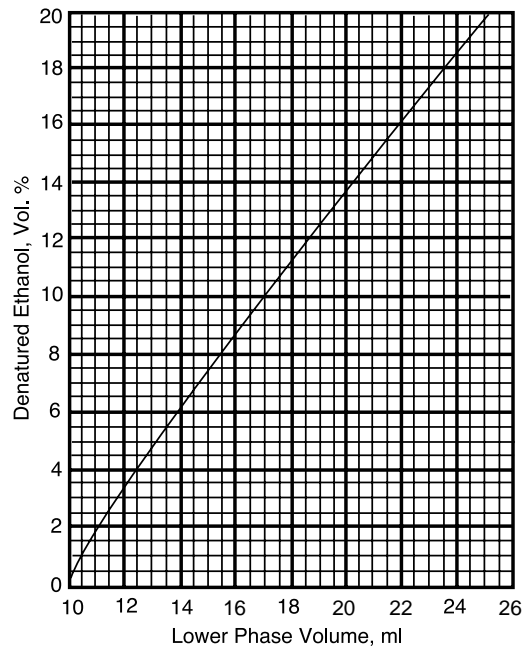
For instance, a reading of approximately 17 ml in the lower phase indicates a presence of approximately 10v% alcohol. This test identifies the level of ethanol present with a reasonable amount of accuracy. This test gives no indication of the fuel's volatility, octane, or other characteristics. Properly formulated, a 10v% ethanol blend would not typically result in driveability problems.

You should not find blends above 10v% ethanol unless the vehicle is a Flex Fueled Vehicle (FFV) or a non-FFV that has been misfueled with a higher level blend intended for use

**Figure 4-5
Alcohol Detection Test**



**Figure 4-6
Volume Percent of Denatured Ethanol in
Gasoline-Water Extraction Method**



in FFVs. All auto manufacturers approve the use of 10v% ethanol blends in their fuel recommendations for all models sold in the U.S.

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

None of these tests measure octane or distillation which are very 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: from the fuel supplier or 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 also 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

State	Phone #	State	Phone #
Alabama	(334) 240-7130	Montana	(406) 841-2240
Alaska	(907) 365-1222	Nebraska	(402) 471-4292
Arizona	(623) 463-9935	Nevada	(775) 688-1166
Arkansas	(501) 570-1159	New Hampshire	(603) 271-3700
California	(714) 680-7871	New Jersey	(732) 815-4842
Colorado	(303) 318-8533	New Mexico	(575) 646-1616
Connecticut	(860) 713-6168	New York	(518) 457-3146
Delaware	(302) 739-5218	North Carolina	(919) 733-3313
District of Columbia	(202) 698-2130	North Dakota	(701) 328-2413
Florida	(850) 488-9740	Ohio	(614) 728-6290
Georgia	(404) 656-3605	Oklahoma	(405) 522-5968
Hawaii	(808) 832-0694	Oregon	(503) 986-4767
Idaho	(208) 332-8690	Pennsylvania	(717) 787-9089
Illinois	(217) 785-8301	Rhode Island	(401) 462-8568
Indiana	(317) 356-7078	South Carolina	(803) 737-9690
Iowa	(515) 725-1493	South Dakota	(605) 773-4091
Kansas	(785) 862-2415	Tennessee	(615) 837-5109
Kentucky	(502) 573-0282	Texas	(512) 463-5706
Louisiana	(225) 925-3780	Utah	(801) 538-7158
Maine	(207) 287-3841	Vermont	(802) 828-3458
Maryland	(410) 841-5790	Virginia	(804) 786-2476
Massachusetts	(617) 727-3480	Washington	(360) 902-1856
Michigan	(517) 655-8202	West Virginia	(304) 722-0602
Minnesota	(651) 296-2990	Wisconsin	(608) 224-4945
Mississippi	(228) 872-4721	Wyoming	(307) 777-6574
Missouri	(314) 452-3620		

Bolded states denote fuel inspection divisions. Other states are Weights & Measures divisions.

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. Technicians could also direct their customers to the Top Tier Detergent gasoline list. If aftermarket additives are utilized, the manufacturer's rec-

ommendations 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 fuel 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 brand of gasoline to see if driveability improves.

NOTES

Chapter 5 Flex-Fuel Vehicles and E85

Introduction

Today more than 8 million vehicles in the U.S. are Flex-Fuel Vehicles (FFVs). Those vehicles can operate on E85 (a blend of 85% denatured ethanol and 15% gasoline), gasoline containing no ethanol, as well as any combination of these fuels. The U.S. automakers have committed to offering nearly 50% of their vehicles as FFVs beginning in 2012. This chapter provides information on FFVs as well as fuel quality information on E85.

FFVs

Although nearly all gasoline fueled passenger cars and light duty trucks sold in the last 20 years have been designed to operate on 10% ethanol blends (E10), substantial modifications are made to FFVs so they can use higher concentrations of ethanol up to E85 without adverse effects on fuel system materials, components, On-board Diagnostics systems ("Service Engine" light), or driveability.

E85 may cause elastomers (rubber) and polymers (plastics) to swell or lose shape and may promote corrosion of some metals. It also increases the electrical conductivity of the fuel and attracts and absorbs small amounts of water. For FFVs, modifications to fuel system materials and components are required such as the fuel pump, fuel level sender, and fuel injectors. Additional sensors and computer capability may also be needed. Although FFV modifications are relatively simple and low cost compared to other alternative vehicles, the extent of the modifications throughout the fuel system and electronic engine control system make field modification of existing vehicles complicated, costly, and impractical.

The list of modified FFV fuel system components includes hoses and other "rubber" components such as fuel pump and fuel pressure regulator diaphragms and fuel injector o-rings to address possible leakage and permeation of fuel and vapor. Modified electrical wiring and connectors are required for submersed components such as the fuel level sender and fuel pump. Increased evaporative emissions carbon canister capacity, a modified fuel tank vapor pressure sensor and modified engine valve and valve seat materials may also be required. Both metal and "plastic" fuel tanks must be designed to accommodate E85. For example, traditional "terne" coated steel fuel tanks and monolayer high density polyethylene fuel tanks are generally not compatible with E85.

A gallon of E85 contains about 75% of the energy contained in a gallon of gasoline (gasoline contains about 114,000 BTU per gallon, while E85 contains about 84,000 BTU per gallon). That means that a flex-fuel vehicle operating on E85 will get about 25% lower miles per gallon compared to operating on gasoline. Therefore the fuel system must be designed to provide sufficient fuel flow including the fuel pump and fuel injectors. To provide sufficient operating range on a tank of fuel, E85 FFVs might also require additional fuel tank capacity.

"Flexible fuel" capability for ethanol concentrations ranging from 0 to 85% involves the use of either a flexible fuel sensor, or a computer calculation based on oxygen sensor information. Many 2006 and later model year FFVs have eliminated the sensor in favor of the computer calculation method. The engine control computer adjusts engine fueling for the reduced energy content and oxygen content of ethanol. Both the reduced energy content and the oxygen content of ethanol requires additional fuel to maintain the proper air-fuel

Figure 5-1
Flex-Fuel Vehicle Features

Engine calibration updates:

Fueling and spark advance calibrations directed by vehicle computer to control combustion, enable cold start and meet emissions requirements

Fuel system electrical connections and wiring: Must be electrically isolated and made of materials designed to handle ethanol's increased conductivity and corrosiveness (if exposed to fuel)

Fuel pump assembly: In-tank components must be made from ethanol-compatible materials and sized to handle the increased fuel flow needed to compensate for ethanol's lower energy density

Internal engine parts: Piston rings, valve seats, valves, and other components must be made of ethanol compatible materials that are designed to minimize the cleansing effects of alcohol fuels which can wash lubrication from parts

Fuel identifier system: Automatically senses the composition of the fuel and adjusts engine for varying ethanol-gasoline blends

Fuel injection system: Must be made of ethanol compatible materials and designed for higher flow to compensate for ethanol's lower energy density

Fuel rail and fuel lines: Must be made of ethanol-compatible materials with seals, gaskets, and rubber fuel hoses rated for ethanol use

Fuel filter assembly: Anti-siphon and spark arrester features are included to handle ethanol's increased conductivity

Fuel tank: Must be made of ethanol-compatible materials and designed to minimize evaporative emissions from ethanol

Source: USDOE-EERE CleanCities Fact Sheet, June 2008

ratio under various engine operating loads and conditions. The different vaporization characteristics of E85 require modified engine fueling strategies under engine cold start and warm up conditions. This requires additional engine control computer capacity, modified software, and different calibrations. Figure 5-1 recaps various FFV features.

How to Identify FFVs: Repair guidelines would be different for an FFV model compared to its non-FFV counterpart. Since September 2006, federal regulations require auto manufacturers to place a label inside the FFV fuel filler compartment that states the vehicle can operate on gasoline or E85. Flex Fuel capability is also encoded in the Vehicle Identification Number (VIN). To determine if an older vehicle is E85 compatible, contact the vehicle manufacturer.

E85 Information

E85 is the trade name for high level ethanol blends sold for use in FFVs. E85 contains 85v% to 75v% denatured ethanol with the remainder being finished gasoline or gasoline hydrocarbon blendstocks. The ranges provide for more

hydrocarbon use in colder months to improve cold start and warm up performance. E85 is most often blended at petroleum products terminals by combining the same ethanol that is used to make E10 with gasoline.

E85 is a finished fuel and like gasoline has an ASTM specification entitled "ASTM D 5798 Standard Specification for Fuel Ethanol (Ed75-Ed85) for Automotive Spark-Ignition Engines". The Ed in the title stands for denatured ethanol. Ethanol is typically denatured with 2 to 5v% hydrocarbons. So Ed85 is typically around 80v% ethanol content while Ed75 might be as low as 70v% ethanol content. The Table 5-1 lists the major properties covered by ASTM D 5798. The following discusses the importance of the property limits in the table.

Ethanol & Higher Alcohols, Hydrocarbons/Aliphatic Ethers, and Vapor Pressure: The limit of the ethanol/higher alcohols and hydrocarbon portion of E85 varies by class. For instance, Class 3 requires less ethanol and allows a lower ethanol minimum. This is done to increase fuel volatility (vapor pressure) to provide better cold start and warm up performance. Class 3 is typically the winter grade, Class 1 the summer grade and Class 2 is typically for fall and spring. The

Table 5-1 ASTM D 5798 Standard Specification for Fuel Ethanol (Ed75-Ed85) for Automotive Spark-Ignition Engines

Properties	Class 1	Class 2	Class 3
Ethanol + higher alcohols, min, volume %	79	74	70
Hydrocarbon/aliphatic ether**, volume %	17-21	17-26	17-30
Vapor pressure, kPa (psi)	38-59 5.5-8.5	48-65 7.0-9.	66-83 9.5-12.0
Sulfur, max, mg/kg	80	80	80
All Classes			
Methanol, volume %, max	0.5		
Higher alcohols (C ₃ -C ₈), max, volume %	2		
Acidity, (as acetic acid CH ₃ COOH), mass % (mg/L), max	0.005 (40)		
Solvent-washed gum content, max, mg/100mL	5		
pH _e	6.5 to 9.0		
Unwashed gum content, max, mg/100 mL	20		
Inorganic chloride, max, mg/kg	1		
Copper, max, mg/L	0.07		
Water, max, mass %	1.0		
Appearance	This product shall be visibly free of suspended or precipitated contaminants (clear and bright). This shall be determined at ambient temperature or 21°C (70°F), whichever is higher.		

** Note that certain states ban the use of MTBE/or other aliphatic ethers.

minimum ethanol and higher alcohols in the specification takes into consideration that the ethanol in the blend is denatured. Thus Class 1 E85, which would typically contain 85% denatured ethanol, is required to meet a 79% minimum ethanol content.

Vapor Pressure: As discussed above, vapor pressure is altered based on historical climate conditions and altitude. Table 2 of ASTM D 5798 lists the appropriate class by state, by month. Class 1 (summer grade) requires a vapor pressure of 5.5-8.5 psi. Class 2 (spring/fall) requires a vapor pressure of 7.0 – 9.5 psi and Class 3 (winter) 9.5 – 12.0 psi. Testing is currently underway to determine if these ranges (established on older vehicle technology) are still appropriate or require revision.

Note: Some states such as California have, or are developing, their own E85 standards.

It is often difficult to meet the minimum vapor pressure requirements with today's lower volatility gasolines. If a customer is complaining of poor cold start and poor warm up performance when operating on E85, it could be because the fuel's vapor pressure is too low. This can be remedied simply by adding more gasoline to the blend.

ASTM is currently assessing the possibility of lowering requirements for the ethanol portion of the blend and increasing the hydrocarbon portion. This would increase vapor pressure for colder climates and/or where gasoline used in the blend is of lower volatility.

Sulfur: Sulfur limits must be controlled because sulfur can damage the catalytic converter.

Methanol and Higher Alcohols: Methanol is held to low limits because it is corrosive, while higher alcohols are controlled to ensure ethanol content.

Acidity, pHe and Inorganic Chloride: These are limited to reduce corrosive properties.

Solvent Washed Gum/Unwashed Gum: Solvent washed gum can contribute to fuel system deposits. The unwashed gum content is set to limit high boiling point components such as diesel fuel. The difference between unwashed and solvent washed gum can be used to determine the presence of non-volatile materials. More analytical testing would be necessary to identify the exact material, which could be additive or additive carrier oils.

Copper: Copper is undesirable in fuels because it can decrease fuel stability.

Water: Water levels are controlled because excessive water levels may increase fuel system corrosion.

Appearance: Controls precipitated contaminants.

Workmanship Clause: Section 5 of ASTM D 5798 also contains a workmanship clause which states:

Fuel Ethanol (Ed75-Ed85) shall be visually free of sediment and suspended matter.

It shall be clear and bright at the ambient temperature of 21°C (70°F), whichever is higher.

The specification defines only a basic purity for fuel ethanol (ED75-Ed85). The product shall be free of any adulterant or contaminant that can render the material unacceptable for its commonly used applications.

Octane: A minimum octane for E85 is not specified. FFV's can tolerate the lower octane of gasoline i.e. 87 (R+M)/2. There is no requirement to post octane on an E85 dispenser. If a retailer chooses to post octane, they should be aware that the often cited 105 octane is incorrect. This number was derived by using ethanol's blending octane value in gasoline. This is not the proper way to calculate the octane of E85. Ethanol's true octane value should be used to calculate E85's octane value. This results in an octane range of 94-96 (R+M)/2. These calculations have been confirmed by actual octane engine tests.

Product Additization: ASTM D 5798 does not contain guidelines for additives such as corrosion inhibitors or detergents/deposit control additives. Work in this area is ongoing.

Detergents/Deposit Control Additives: Recent studies have shown that E85 may, in some cases, lead to development of fuel injector and/or intake valve deposits. Preliminary work indicates that this may be a result of no detergents in the ethanol portion of the blend in combination with high levels of corrosion inhibitor. This situation will likely be remedied as E85 sales increase. In the interim, the problem, if present, can be corrected by using one or two tanks of Top Tier Detergent gasoline (see discussion page 22).

Gasoline Gallon Equivalence (GGE): E85 blends contain less energy than gasoline, which results in fewer miles per gallon. Fuel cost, on a miles driven basis, must be considered. This is sometimes called gasoline gallon equivalence (GGE). This is where things get a little more complicated. First, E85 is really E75 in the winter, E80 in spring and fall, and E85 in summer. Ethanol does not contain as much energy as gasoline (lower btu/gallon). In fact, E85 (E75, E80) contains about 73% to 76% the btu content of gasoline. The actual impact on fuel economy can vary depending on vehicle driving patterns, driving conditions, driver input, state of tune and other factors. While some drivers and fleets have experienced fuel economy penalties below 10% most drivers will experience a miles per gallon drop corresponding somewhat to the btu content level. Since E85 may improve engine thermal efficiency, a small portion of the lower btu value may be offset. It does not take the consumer long to figure out that they cannot go as far on a tankful of E85 as on one of gasoline. To offer comparable value the consumer must be able to drive the same distance on a dollar's worth of E85 as a dollar's worth of gasoline. The price of E85 is set by the retailer. However, to provide the consumer with information on how they might compare E85 on a cost per mile or GGE basis, a hypothetical example is provided in Table 5-2. In the example in the table the consumer pays less per gallon for E85 since fewer miles per gallon are achieved. However, the driving cost to the consumer is approximately the same. The example in Table 5-2 is based on average btu values. The actual btu value of

**Table 5-2
E85 Gasoline Gallon Equivalence**

	<u>Gasoline</u>	<u>E75</u>	<u>E85</u>
Gasoline Portion	\$2.15	\$0.5375	\$0.3225
Ethanol Portion	\$0.0	\$1.095	\$1.2410
Total	\$2.15	\$1.6325	\$1.5635
% of Gasoline Price	100%	76.0%	72.7%

Ethanol price \$1.91 per gallon less \$0.45 credit = \$1.46. Unleaded regular \$2.15 per gallon

the hydrocarbon portion can vary. Also, the table does not consider any improvements in thermal efficiency when operating on E85. If a consumer gets 20 mpg on gasoline and 15 mpg on E85, that's 400 miles on 20 gallons of gasoline and only 300 miles on E85. They will not be willing to use E85 unless the cost per mile driven is similar to that of gasoline.

While there is no requirement to post the octane value of E85 on the retail dispenser, the Federal Trade Commission (FTC) does require an alternative fuel label. This label must identify the fuel as E85 and state the minimum volume percentage of ethanol present. An example of such a label is depicted in Figure 5-2. It is also recommended (and in some areas required) that the dispenser or nozzle have a consumer advisory label that states this fuel is for use in FFV's only.

**Figure 5-2
FTC Alternative Fuel Label**



Chapter 6 The Use of Gasoline and Gasoline Ethanol Blends in Non-Automotive Engines

Background

Over the years there has been a great deal of confusion about the use of fuels in various non-automotive applications. Programs requiring the increased use of ethanol 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 the "Changes in Gasoline" manual. Accordingly, this chapter of the manual provides information on this topic.

First it should be noted that all gasoline 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, most 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. However, there are also expensive items in this category such as gasoline powered boats and yachts.

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, 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.

During the 1980s 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 market share 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 1990s 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.

Gasoline Ethanol Blends

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 overblends (i.e. blends containing more than legally permitted levels of ethanol). The following provides more detail on each topic.

Materials Compatibility: Ethanol has been extensively tested for its affect 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 ethanol 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 ethanol blends. This is evidenced by their fuel recommendation comments which now permit the use of such fuels in their equipment marketed in the U.S. 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 data available indicates that properly formulated gasoline ethanol blends may provide slightly better lubricity.

Enleanment: Oxygenates such as ethanol 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 3.5% oxygen in the fuel would enlean the A/F ratio to about 15.2:1. 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 ethanol blends should not present problems in the area of octane quality because ethanol is actually an octane enhancer. Ethanol is 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 older carbureted sleds "jet up" one size when operating on oxygenates. Further, some of their fuel injected 2 cylinder models require 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. Arctic Cat recommends that when using oxygenated fuels in their older 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: Ethanol attracts moisture. If excessive moisture is absorbed, the ethanol and water can phase separate (fall out of suspension) from the gasoline blend. This would result in a mixture of ethanol and water in the bottom of the fuel tank. Aside from the fact that the engine would not operate on this ethanol/water blend, it can also

cause corrosion of various metals with which it comes in contact. However the potential for phase separation must be put in perspective. 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. These concerns can be addressed simply by exercising caution that no water is introduced into the system. These precautions include 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 three or four months.

Over-Blending: Manufacturers of gasoline ethanol blends 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.

Not all manufacturers mention gasoline ethanol blends either as approved or not approved. Most of these manufacturers rely on the engine manufacturer's recommendation. However the Outdoor Power Equipment Institute has indicated that all the existing equipment manufactured by their members are compatible with up to 10% ethanol. If there are any doubts about a manufacturer's position, it is recommended that the manufacturer or an authorized dealer be consulted. Among the listed manufacturers that specifically mention ethanol, 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 gasoline ethanol blends are acceptable. Of course, today gasoline ethanol blends are the only fuel available in most markets. 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 on older models for proper operation on ethanol blends.

Marine manufacturers tend to utilize the most negative wording regarding oxygenates such as ethanol. This may be due in part to their concerns about the potential for phase separation of ethanol 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.

Of special concern is older in-hull fiberglass tanks. The polyester resins used in the fiberglass of older watercraft (generally prior to 1991) may not be compatible with ethanol blends. There have been reports of tanks being negatively affected. Many of these were on older Bertrams or Hatterases, both of which are popular in coastal areas. It appears that the ethanol may cause softening of the resin, thereby reducing adhesion between the fiber and the resin. Aside from the obvious risk of tank failure, these materials break down into products, such as styrene and phthalates, which become dispersed into the gasoline leading to increased carburetor and intake valve deposits to the extent that it can cause engine damage.

Gasoline-ethanol blends should not be used in these older watercraft tanks. If ethanol free gasoline is not available, the boat must be retrofitted with compatible fuel storage tanks.

The following provides information on the position some of the larger non-automotive engine and equipment manufacturers take on ethanol. The information excerpts have been collected from manufacturer websites and equipment owners manuals. Note that, unlike vehicle owners manuals which can be identified by model year, this is not the case with equipment owners manuals.

• **Briggs & Stratton (Website-2009)**

All 4 stroke cycle spark ignition engines

Fuel must meet these requirements

- Clean, fresh unleaded gasoline
- A minimum of 87 octane/87 AKI (91 RON). High Altitude use, see below.
- Gasoline with up to 10% ethanol (gasohol) or up to 15% MTBE (methyl tertiary butyl ether) is acceptable.

Caution: Do not mix oil in gasoline or modify engine to run on alternative fuels. This will damage the engine components and void the engine warranty.

To protect the fuel system from gum formation, mix in a fuel stabilizer when adding fuel. See storage section below.

All fuel is not the same. If starting or performance problems occur, change fuel providers or change brands. This engine is certified to operate on gasoline. The emissions control system for this engine is EM (Engine Modification).

High Altitude

At altitudes over 5,000 feet (1524 meters), a minimum 85 octane/85 AKI (89 RON) gasoline is acceptable. To remain emissions compliant, high altitude adjustment is required. Operation without this adjustment will cause decreased performance, increased fuel consumption, and increased emissions. See an Authorized Briggs & Stratton Dealer for high altitude adjustment information.

Operation of the engine at altitudes below 2,500 feet (762 meters) with the high altitude kit is not recommended.

All 2 stroke cycle spark ignition engines

Mixing fuel and oil

Always mix a high-quality, 2-cycle oil, such as Briggs & Stratton 2-cycle oil, at 50:1 gasoline to oil ratio.

Fuel must meet these requirements:

- Clean, fresh unleaded gasoline
- A minimum of 87 octane/87 AKI (91 RON). High Altitude use, see below.
- Gasoline with up to 10% ethanol (gasohol) or up to 15% MTBE (methyl tertiary butyl ether) is acceptable.

Caution: Do not use unapproved gasoline such as E85*. Do not modify engine to run on alternative fuels. This will damage the engine components and void the engine warranty.

To protect the fuel system from gum formation, mix in a fuel stabilizer when adding fuel.

See Storage section below

All fuel is not the same. If starting or performance problems occur, change fuel providers or change brands. This engine is certified to operate on gasoline. The emissions control system for this engine is EM (Engine Modification).

High Altitude

At altitudes over 5,000 feet (1524 meters), a minimum 85 octane/85 AKI (89 RON) gasoline is acceptable. To remain emissions compliant, high altitude adjustment is required. Operation without this adjustment will cause decreased performance, increased fuel consumption, and increased emissions. See an Authorized Briggs & Stratton Dealer for high altitude adjustment information.

Operation of the engine at altitudes below 2,500 feet (762 meters) with the high altitude kit is not recommended.

Storage

Fuel will become stale when stored over 30 days. Stale fuel causes acid and gum deposits to form in fuel system or on essential carburetor parts. To keep fuel fresh, use Briggs & Stratton FRESH START™ fuel stabilizer, available as a fuel stabilizer or a drip concentrate cartridge.

There is no need to drain gasoline from the engine if a fuel stabilizer is added according to instructions. Run the engine for 2 minutes to circulate the stabilizer throughout the fuel system. The engine and fuel can then be stored up to 24 months.

If gasoline in the engine has not been treated with a fuel stabilizer, it must be drained into an approved container. Run the engine until it stops from lack of fuel. The use of a fuel stabilizer in the storage container is recommended to maintain freshness. It is also recommended that fuel is purchased in quantities that can be used within 30 days. This will assure fuel freshness and volatility tailored to the season.

*NOTE: Briggs & Stratton engines are not designed to run on

E85 fuel. E85 is a blend of 85% ethanol (alcohol) and 15% gasoline, which is not compatible with most engines intended to run on regular gasoline. While alcohol is an excellent octane booster, it delivers less power, having an energy content value of only about 77,000 Btu per gallon versus 114,000 Btu for regular gasoline. E85 also demands a different fuel-to-air ratio to burn efficiently, requiring specially calibrated carburetors. Further, specially designed fuel system components are required to withstand the high alcohol concentration found in E85.

• **Tecumseh (Owners manual-2008)**

Fuel

Use unleaded regular, unleaded premium or reformulated automotive fuel only. You may use gasoline containing the components identified in Table 3.

- DO NOT use leaded fuel.

Table 3. Recommended Fuel	
Fuel Component	Percentage
Ethanol	10%
Grain Alcohol (Gasohol)	10%
MTBE (Methyl Tertiary Butyl Ether)	15%
ETBE (Ethyl Tertiary Butyl Ether)	15%

Fuel must be fresh and clean. NEVER use fuel left over from last season or stored for long periods.

- NEVER mix oil with fuel.
- DO NOT use fuel containing methanol (wood alcohol).

CAUTION: The use of alternative fuels such as E85 or E20 are NOT recommended for use in Tecumseh Power engines. Alternative fuels with high alcohol content can cause hard starting, poor engine performance, and may cause internal engine damage.

NOTE

Damage and/or performance problems that occur from use of fuels other than those listed in the Operator's Manuals will not be considered warranty.

• **Kohler (Owners manual-2009)**

General Recommendations

Purchase gasoline in small quantities and store in clean, approved containers. A container with a capacity of 2 gallons or less with a pouring spout is recommended. Such a container is easier to handle and helps eliminate spillage during refueling.

Do not use gasoline left over from the previous season to minimize gum deposits in your fuel system and to ensure easy starting.

Do not add oil to the gasoline.

Do not overfill the fuel tank. Leave room for the fuel to expand.

Fuel Type

For best results use only clean, fresh, unleaded gasoline with the pump sticker octane rating of 87 or higher. In countries

using the Research method, it should be 90 octane minimum.

Unleaded gasoline is recommended as it leaves less combustion chamber deposits and reduces harmful exhaust emissions. Leaded gasoline is not recommended and must not be used on EFI engines, or on other models where exhaust emissions are regulated.

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 including E20 and E85 are not to be used and not approved. Any failure resulting from use of these fuels will not be warranted.

• **Harley Davidson (Owners manual-2009)**

GASOLINE BLENDS

Your motorcycle was designed to get the best performance and efficiency using unleaded gasoline. Most gasoline is blended with alcohol and/or ether to create oxygenated blends. The type and amount of alcohol or ether added to the fuel is important.

CAUTION

Do not use gasoline that contains methanol. Doing so can result in fuel system component failure, engine damage and/or equipment malfunction.

- Gasoline 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 is a mixture of 10% ethanol (Grain alcohol) and 90% unleaded gasoline. Gasoline/ethanol blends can be used in your motorcycle if the ethanol content does not exceed 10%.

- REFORMULATED OR OXYGENATED GASOLINE (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.

- Do not use race gas or octane boosters. Use of these fuels will damage the fuel system.

Some gasoline blends might adversely affect the starting, driveability or fuel efficiency of the motorcycle, If any of these problems are experienced, try a different blend of gasoline or gasoline with a higher octane blend.

• **Honda (Owners manual-2009)**

ADDITIONAL INFORMATION

Oxygenated Fuels

Some conventional gasolines are blended with alcohol or an ether compound. These gasolines are collectively referred to as oxygenated fuels. To meet clean air standards, some

areas of the United States and Canada use oxygenated fuels to help reduce emissions.

If you use an oxygenated fuel, be sure it is unleaded and meets the minimum octane rating requirement.

Before using an oxygenated fuel, try to confirm the fuel's contents. Some states/provinces require this information to be posted on the pump.

The following are the EPA approved percentages of oxygenates:

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 Ethyl) 15% by volume. You may use gasoline containing up to 15% MTBE by volume.
Methanol - (Methyl or wood alcohol) 5% by volume. You may use gasoline containing up to 5% methanol by volume, as long as it also contains cosolvents and corrosion inhibitors to protect the fuel system. Gasoline containing more than 5% methanol by volume may cause starting and/or performance problems. It may also damage metal, rubber, and plastic parts of your fuel system.

If you notice any undesirable operating symptoms, try another service station or switch to another brand of gasoline.

Fuel system damage or performance problems resulting from the use of an oxygenated fuel containing more than the percentages of oxygenate mentioned above are not covered under warranty.

• Mercury Marine (Website Service & Warranty-2009)

Ethanol

What are the characteristics of ethanol?

Ethanol is an oxygenated hydrocarbon compound that has a high octane rating and therefore is useful in increasing the octane level of unleaded gasoline. The EPA, the agency responsible for setting some of the requirements for all gasoline used in the U.S. has allowed the use of ethanol in gasoline at levels up to 10 percent as an octane enhancer and to provide beneficial clean-burning combustion characteristics that help improve some emissions.

Ethanol is hygroscopic (it has an attraction for water) and will more readily mix with water than with gasoline. It has different solvency behaviors than does gasoline, which allows it to loosen rust and debris that might lay undisturbed in fuel systems. And it can more readily remove plasticizers and resins from certain plastic materials that might not be affected by gasoline alone. Loose debris will plug filters and can interfere with engine operation. Additionally, ethanol is corrosive to some metals, especially in combination with water. Although gasoline does not conduct electricity well, ethanol has an appreciable capability to conduct electricity and therefore can promote galvanic corrosion.

Does ethanol affect horsepower or fuel-efficiency?

Ethanol has a heating value of 76,000 BTU per gallon, which

is approximately 30 percent less than gasoline's heating value (which is approximately 109,000 to 119,000 BTU/gal). The result is E-10 gasoline which should yield slightly lower mileage—a decrease of approximately 3 percent. Fuels containing higher levels of ethanol will have a corresponding reduction in mileage. For example, E85 fuels produce mileage approximately 30 percent less than gasoline.

The octane rating of pure ethanol (200 proof) is about 100 and is therefore useful in elevating the octane value of gasoline. In E-10 blends the presence of ethanol provides about 2.5 to 3 percent of the overall octane rating. The effect on engine horsepower is determined by the octane result of the blended fuel. Care should be taken to select fuels having the octane rating recommended for the engine as indicated in the owner's manual for proper operation.

Are Mercury engines compatible with ethanol fuels?

The fuel-system components of Mercury engines will withstand up to 10 percent ethanol in gasoline—the maximum level currently allowed by the EPA in the U.S. There are some efforts to establish E-20 (20 percent ethanol mixed with 80% gasoline) for use in some areas, but that will require agreement from EPA to grant a waiver. Part of the EPA waiver process will require verification from studies that demonstrate that higher levels of ethanol do not create problems with fuel-system materials or operation of hardware. E-20 has not been extensively studied by Mercury and is not acceptable for use in Mercury products. E-85 fuels must not be used in any Mercury engines and could seriously damage current Mercury products. It is not legal in the U.S. to market any ethanol fuel as gasoline if it contains more than 10 percent ethanol.

Will the use of fuels containing ethanol void my engine warranty?

Fuels containing up to 10 percent ethanol are considered acceptable for use in Mercury engines. Fuels containing higher levels of ethanol are not considered acceptable for use, and the use of fuels containing ethanol higher than 10 percent can void the warranty.

What about the fuel-system components on the boat?

It is important to follow boat manufacturers' recommendations when selecting appropriate fuels. Use of an inappropriate fuel can result in damage to the engine and boat components that may require repair or replacement. Fuels with ethanol can attack some fuel-system components, such as tanks and lines, if they are not made from acceptable ethanol-compatible materials. This can lead to operational problems or safety issues such as clogged filters, leaks, or engine damage.

Can ethanol-blended fuels affect the performance of traditional carbureted two-stroke outboards?

Two-stroke outboards should experience little or no decrease in performance due to gasoline fuels containing up to 10-percent ethanol when operated according to Mercury's standard recommendations. When gasoline with ethanol is used for the first time after a fuel changeover from MTBE, the tank must be completely free of water prior to introduction of gasoline with ethanol. Otherwise phase separation could occur that could cause filter plugging or damage to the engine. (It is probably better for a boat owner to fill the fuel tank with ethanol fuel for the first time when the tank is low on fuel, but

that is not critical. There should be no difficulties if the tank is clean and free from water. If the tank is not free from water, a partial load of fuel will more easily phase separate because with less ethanol in place it takes less water to cause phase separation. The important thing for boaters to concern themselves with is the presence of water in their tanks.)

If an engine is a 1990 or older model, frequent inspections of all fuel-system components are advised to identify any signs of leakage, softening, hardening, swelling, or corrosion. If any sign of leakage or deterioration is observed, replacement of the affected components is required before further operation.

How does ethanol affect my fiberglass fuel tank?

Fiberglass tanks manufactured prior to 1991 may not be compatible with gasoline containing ethanol. It has been reported that, in the presence of ethanol, some resins may be drawn out of fiberglass and carried into the engine where severe damage could occur. If an older fiberglass tank is used, check with the manufacturer to determine if gasoline with ethanol can be safely used.

Are older fuel lines prone to failure? What about gaskets?

During the 1980s, many rubber components for use in the fuel systems were developed to withstand exposure to fuels containing ethanol. If rubber components in a fuel system are suspected to be of this vintage or older it may be advisable to replace them with newer ethanol-safe components before using fuels containing ethanol. Check with the manufacturer for advice or frequently inspect these fuel-system components for signs of swelling or deterioration and replace if problems are noted.

Should I add an additional fine-micron filter to the system to prevent debris from entering the engine?

The addition of another filter to the system will create another possible flow restriction that can starve the engine of fuel. Mercury already provides the appropriate level of filtration to protect the engine from debris.

What is phase separation, and how do I deal with it?

If significant amounts of water are present in a fuel tank with gasoline that contains ethanol, the water will be drawn into the fuel until the saturation point is reached for the three-component mixture of water + gasoline + ethanol. Beyond this level of water, phase separation could cause most of the ethanol and water to separate from the bulk fuel and drop to the bottom of the tank, leaving gasoline with a significantly reduced level of ethanol in the upper phase. If the lower phase of water and ethanol is large enough to reach the fuel inlet, it could be pumped directly to the engine and cause significant problems. Even if the ethanol water phase at the bottom of the tank is not drawn into the fuel inlet, the reduced ethanol level of the fuel reduces the octane rating by as much as 3 octane numbers, which could result in engine problems.

The level at which phase separation can occur is determined by a number of variables, including the amount of ethanol, the composition of the fuel, the temperature of the environment and the presence of contaminants. It is very important (A) that the system is inspected for significant quantities of water in the tank before using gasoline with ethanol and (B) to limit exposure of the fuel tank to excess water. If phase separation

has occurred, it is necessary to completely remove all free water from the system and replace the fuel before continuing operation. Otherwise, engine problems could occur.

Is an additive available that can prevent phase separation? There is no practical additive that can prevent phase separation from occurring. The only practical solution is to keep water from accumulating in the tank in the first place.

Are there any additives that can allow the phase-separated mixture to remix when added to the fuel tank?

No, the only way to avoid the further problems is to remove the water, dispose of the depleted fuel, clean the tank and start with a fresh, dry load of fuel.

If there a simple solution to water condensation in the tank as a result of ethanol?

It is best to maintain a full tank of fuel when the engine is not in use. This will reduce the void space above the fuel and will reduce the flow of air in and out of the tank with changes in temperature. This will reduce condensation on the internal walls of the tank and will limit exposure of the ethanol in the fuel to humidity and condensation.

What should be done when storing boats with ethanol-blended fuels for extended periods?

Follow the instructions for normal storage preparation found in the owner's manual or operations guide. When preparing to store a boat for extended periods of two months or more, it is best to completely remove all fuel from the tank. If it is difficult or not possible to remove the fuel, maintaining a full tank of fuel with a fuel stabilizer added to provide fuel stability and corrosion protection is recommended. It is best to add the stabilizer and fuel treatment to the tank at the recommended dosage, running the engine for 10 minutes to allow the system to be cleaned, shutting off the fuel valve to interrupt the fuel supply and allow the engine to run until it stops, topping off the tank until it's full to reduce the amount of exchange with the air that might bring in condensation. Do not cap the tank vent and do not fill with fuel to the point of overflowing. Some extra space should be maintained in the tank to allow for expansion and contraction of the fuel with temperature changes. A partially full tank is not recommended because the void space above the fuel allows air movement that can bring in water through condensation as the air temperature moves up and down. This condensation could potentially become a problem.

Mercury Marine Fuel System Treatment & Stabilizer can help maintain fuel systems in storage. It contains oxidation inhibitors to reduce oxidation and gum formation, metal chelating agents to protect metal components from corrosion, water absorbing agents to reduce the presence of free water, and dispersants to help suspend and disperse debris. When placing the boat back in service, be sure to reopen the fuel valve to the engine.

• **Kawasaki (older owners manual)**

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.

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.

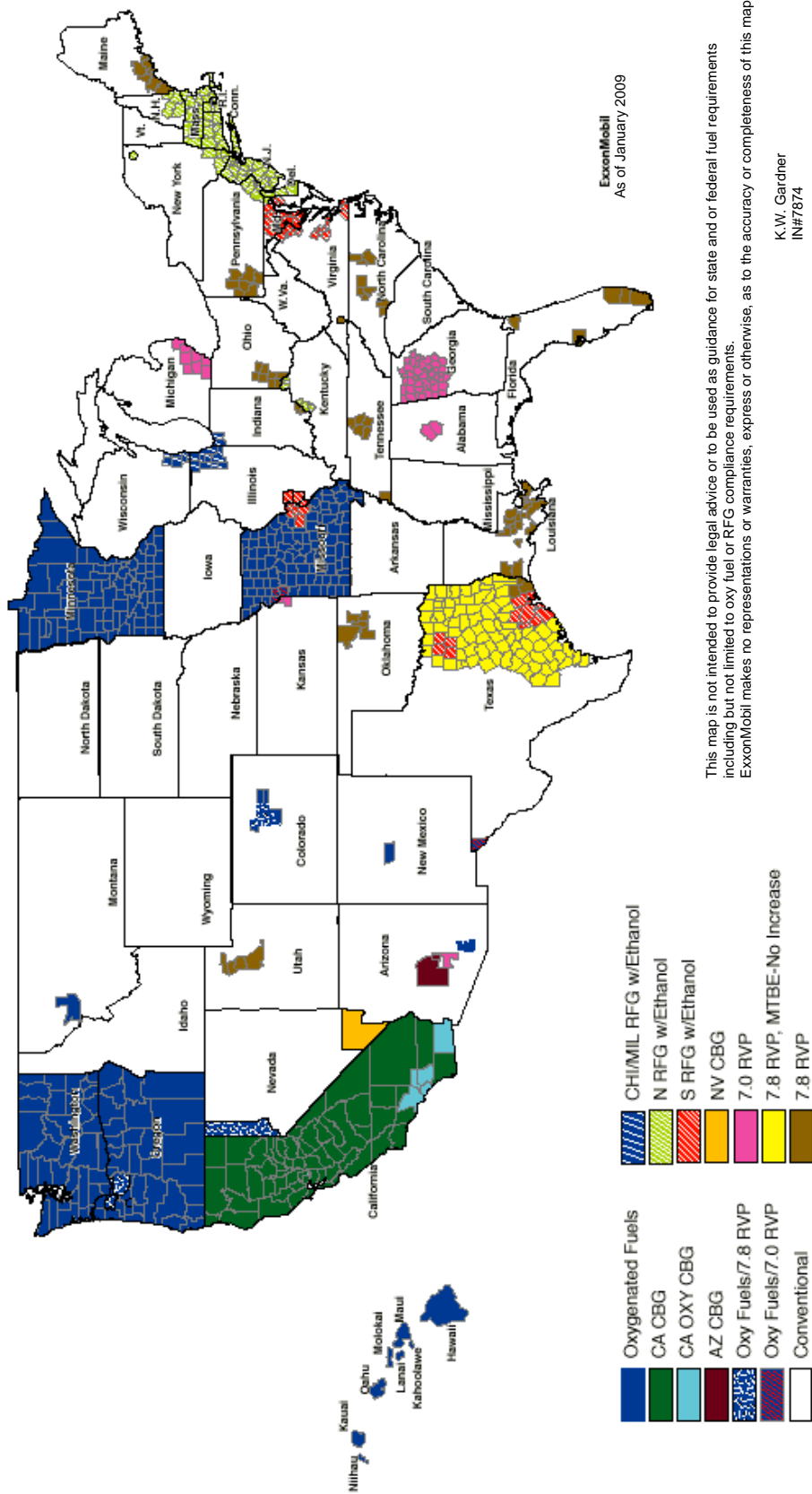
If information is unclear or insufficient, an authorized dealer for the applicable brand of equipment should be consulted.

Consumers should be advised that if they are purchasing new equipment, they should ensure that the manufacturer permits the use of gasoline ethanol blends. Due to existing federal regulations, it is anticipated that nearly all gasoline sold in the U.S. will contain ethanol. No one wants to purchase a product that will not operate satisfactorily on the available fuel supply.

The facts demonstrate that gasoline ethanol blends 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.

Appendix A Gasoline Program Areas

Figure A-1 U.S. Gasoline Requirements



This map is not intended to provide legal advice or to be used as guidance for state and/or federal fuel requirements including but not limited to oxy fuel or RFG compliance requirements. ExxonMobil makes no representations or warranties, express or otherwise, as to the accuracy or completeness of this map.

K.W. Gardner
INH7874

Source: American Petroleum Institute

Appendix B 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 B-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 B-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 B-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 B-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 B-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
Nitrophenyl® (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
<p>Note (1) Manufacturer data suggests that Viton® & fluoroelastomers are the preferred materials for use with alcohols, ethers, and higher concentrations of aromatics.</p> <p>Note (2) In some tests, parts composed of Epichlorohydrin have shown signs of deterioration when exposed to high concentrations of MTBE.</p>	

Appendix C Glossary of Industry 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.

ASTM International: 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 reformulated gasoline program) from resulting in any higher levels of emissions than their EPA designated baseline fuel.

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.

Boutique Fuels: Gasoline unique to certain areas that have more stringent specifications than conventional gasoline but less stringent than RFG.

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 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.

CO: Carbon monoxide

CO₂: Carbon dioxide

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 are required to use this model to develop their reformulated gasoline.

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.

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: A hydrocarbon component of gasoline which contributes to gum and lacquer formation in the fuel system and engine.

DISI: Direct injection spark ignition.

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).

E85: An ethanol blend typically comprised of 85v% to 75v% denatured ethanol with the remainder of the blend being gasoline or hydrocarbon components present in gasoline.

EISA2007: Energy Independence and Security Act of 2007.

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.

EPA: U.S. Environmental Protection Agency.

EPACT 2005: The Energy Policy Act of 2005.

Ethanol (ethyl alcohol, grain alcohol): Typically fermented from the starch found in 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 up to 85 volume percent as a fuel in FFVs.

Flex-Fuel Vehicle (FFV): A vehicle that is capable of operating on E85 or 100% gasoline or any mixture of the two.

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 with the term E10.

GHG: Greenhouse gas

HC: Hydrocarbon

kg: Kilogram

Lead (tetraethyl lead): An organometallic octane enhancer. One gram of lead compound increases the octane of one gallon of gasoline about six numbers. Lead is not permitted in U.S. gasoline (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.

mg: Milligram

ml: Milliliter

NMOG: Non-methane organic gases

NOx: Oxides of Nitrogen

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 and ethanol.

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.

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

Oxygenated Gasoline: Gasoline containing an oxygenate such as ethanol. Provides chemical enrichment of the A/F charge

thereby improving combustion and reducing tailpipe emissions of CO.

Ozone: Ozone (O₃) is formed when oxygen (O₂) 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.

PM : Particulate matter

ppm: Parts per million.

Predictive Model: Similar to EPA's Complex Model and used to regulate reformulated gasoline sold in California.

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.

RFS: Renewable Fuels Standard

Toluene: An aromatic compound used to increase octane. One of the more common hydrocarbons purchased for use in increasing octane. Basic aromatic in the BTX group.

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.

Vapor Pressure (VP): 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.

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 (w%): 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. Basic aromatic in the BTX group.

Changes in Gasoline IV was prepared specifically to provide information about spark ignition fuel quality to automotive service professionals, instructors, and automotive students, as well as the small engine service technician. It is based on a review of over 150 reference documents and was reviewed by a technical panel to ensure technical accuracy. In addition, an advisory board provided review and input to help focus the manual on issues of key interest to the auto service/repair industry.

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