WHITE PAPER:
PETROLEUM PRODUCTION, DISTRIBUTION AND DISCUSSION OF THE USE OF ETHANOL BLENDED GASOLINE

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I. REFINING

I. REFINING

This section focuses on refining, the complex series of processes that manufacturers finished petroleum products out of crude oil and other hydrocarbons. While refining began as simple distillation, refiners must use more sophisticated additional processes and equipment in order to produce the mix of products that the market demands. Generally, this latter effort minimizes the production of heavier, lower value products (for example, residual fuel oil) in favor of lighter, higher value products (for example, gasoline).

Simple Distillation

The core refining process is simple distillation, (see illustrations at section end). Because crude oil is made up of mixture of hydrocarbons, this first and basic refining process is aimed at separating the crude oil into its “fractions”, the broad categories of its component hydrocarbons. Crude oil is heated and put into a still – a distillation column – and different products boil off and can be recovered at different temperatures. The lighter products – liquid petroleum gases (LPG), naphtha, and so-called “straight run” gasoline – are recovered at the lowest temperatures. Middle distillates – jet fuel, kerosene, distillates (such as home heating oil and diesel fuel) – come next. Finally, the heaviest products (residuum or residual fuel oil) are recovered, sometimes at temperatures over 1000 degrees F. The simplest refineries stop at this point. Most in the United States, however, reprocess the heavier fractions into lighter products to maximize the output of the most desirable products.

Downstream Processing

Additional processing follows crude distillation, “downstream” (or closer to the refinery gate and the consumer) of the distillation process. Downstream processing is grouped together in this discussion, but encompasses a variety of highly complex units designed for very different upgrading processes. Some change the molecular structure of the input with chemical reactions, some in the presence of a catalyst, some with thermal reactions.

In general, these processes are designed to take heavy, low-valued feedstock – often itself the output from an earlier process – and change it into lighter, higher-valued output. A catalytic cracker, for instance, uses the gasoline (heavy distillate) output from crude distillation as its feedstock and produces additional finished distillates (heating oil and diesel) and gasoline. Sulfur removal is accomplished in a hydrotreater. A reforming unit produces higher octane components for gasoline from lower octane feedstock that was recovered in the distillation process. A cooker uses the heaviest output of distillation, the residue or residuum, to produce a lighter feedstock for further processing, as well as petroleum coke.

As noted above, U.S. demand is centered on light products, such as gasoline. Refiners in the United States more closely match the mix of products demand by using downstream processing to move from the natural yield of products from simple distillation, illustrated earlier, to the U.S. demand sale, illustrated here. After simple distillation alone, the output from the crude oil like Arab Light would be about 20 percent of lightest, gasoline-like products, and about 50 percent of the heaviest, the residuum. After further processing in the most sophisticated refinery, however, the finished product output is about 60 percent gasoline, and 5 percent residuum.

Crude Oil Quality

The physical characteristics of crude oils differ. Crude oil with a similar mix of physical and chemical characteristics, usually produced from a given reservoir, field or sometimes even a region, constitutes a crude oil "stream". Most simply, crude oils are classified by the density and sulfur content. Less dense (or "lighter") crude's generally have a higher share of light hydrocarbons – higher value products – that can be recovered with simple distillation. The denser ("Heavier") crude oils produce a greater share of lower-valued products with simple distillation and require additional processing to produce the desired range of products. Some crude oils also have a higher sulfur content, an undesirable characteristic with respect to both processing and product quality. For pricing purposes, crude oils of similar quality are often compared to a single representative crude oil, a "benchmark" of the quality class.

The quality of the crude oil dictates the level of processing and re-processing necessary to achieve the optimal mix of product output. Hence, price and price differentials between crude oils and also reflect the relative ease of refining. A premium crude oil like West Texas intermediate, the U.S. benchmark, has a relatively high natural yield of desirable naphtha and straight-run gasoline. Another premium crude oil, Nigeria's Bonny Light, has a high natural yield of middle distillates. By contrast, almost half of the simple distillation yield from Saudi Arabia's Arabian Light, has a high natural yield of middle distillates; almost half of the simple distillation yield from Saudi Arabia's Arabian Light, the historical benchmark crude, is a heavy residue ("residuum") that must be reprocessed or sold at a discount to crude oil. Even West Texas Intermediate and Bonny Light have a yield of about one-third residuum after the simple distillation process.

In addition to gravity and sulfur content, the type of hydrocarbon molecules and other natural characteristics, may affect the cost of processing or restrict of crude oil's suitability for specific uses. The presence of heavy metals, containments the processing and for the finished product, is one example. The molecular structure of a crude oil also dictates whether a crude stream can be used for the manufacture of specialty products such a lubricating oils or of petrochemical feedstocks.

Refiners therefore, strive to run the optimal mix (or "slate") of crudes through their refineries, depending on the refinery's equipment, the desired output mix, and the relative price of available crudes. In recent years, refiners have confronted two opposite forces – consumer's and government mandates that increasingly required light products of higher quality (the most difficult to produce) and crude oil supply that was increasingly heavier, with higher sulfur content (the most difficult to refine).

Other Refinery Inputs

In addition to crude oil that runs through a simple distillation, a variety of other specialized inputs, usually to downstream units, enhance the refiner's capability to make the desired mix of products. Among these products might be unfinished (partly refined) oil, or imported residual fuel oil used as input to a vacuum distillation unit. The supply patter for "reformulated gasoline" or RFG, the mandated low-pollution product first required in 1995, includes an important share of blending components that are classified as refinery inputs. These blending components include oxygenates but consist mainly of products that could be classified as finished gasoline in other jurisdictions or products that require little additional blending to be classified as finished gasoline. While they are counted as "refinery inputs," they are brought to saleable specification in terminals and blending facilities, not in conventional refineries.

U.S. refining capacity, as measured by daily processing capacity of crude oil distillation units alone, has appeared relatively stable in recent years, at about 16 million barrels per day of operable capacity. While the level is a reduction from the capacity of twenty years ago, the first refineries that were shut down as demand fell in the early 1980's were those that had little downstream processing capability. Limited to simple distillation, these small facilities were only economically viable while receiving subsidies under the Federal price control system that ended in 1981. Some additional refineries were shut down in the last 1980's and during the 1990's, always, of course, those at the least profitable end of a company's asset portfolio. At the same time, refiners improved the efficiency of the crude oil distillation units that remained in service by "debottlenecking" to improve the flow and to match capacity among different units and by turning more and more to computer control of the processing. Furthermore, following government mandates for environmentally more benign products as well as commercial economics, refiners enhanced their upgrading (downstream processing) capacity. As a result, the capacity of the downstream units ceased to be the constraining factor on the amount of crude oil processed (or "run") through the crude oil distillation system. Thus crude oil inputs to refineries ("runs") have continued to rise, and along with them – given the stability of crude oil distillation capacity – capacity "utilization" rose throughout much of the 1990's. Utilization – the share of capacity filled with crude oil – reached truly record levels in the last half of the decade, nominally exceeding 200 percent for brief periods.

As with most aspects of the U.S. oil industry, the <u>Gulf Coast is by far the leader in refinery capacity</u>, with more than twice the crude oil distillation capacity as any other United States region. (The difference is even greater for downstream processing capacity, because the Gulf Coast has the highest concentration of sophisticated facilities in the world.) The Gulf Coast is the nation's leading supplier in refined products as in crude oil. It ships refined product to both the East Coast (supplying more than half of that region's needs for light products like gasoline, heating oil, diesel, and jet fuel) and to the Midwest (supplying more than 10 percent of the region's light product consumption.)

There are seasonal pattern in refinery input. In the United States, refinery runs mirror the overall demand for products – lower in the colder months and higher in the warmer months. In addition, as they move out of the gasoline season in the early autumn and then as they move into the next gasoline season in the late winter, refiners routinely perform maintenance. The duration and depth of the cutback in refining activity during each maintenance season is affected by a variety of factors, including the relative strength of the market for refined products. Therefore, when stocks are high and demand slack, the refinery maintenance season is likely to be longer and deeper. Refinery activity will also respond to the market's need (and hence relative prices) for product, with changes in the level of crude oil throughput as well as emphasis on one product over another.

World Refining Capacity

Broadly speaking, refining developed in consuming areas, because it was cheaper to move crude oil than to move product. Furthermore, the proximity to consuming markets made it easier to respond to weather-induced spikes in demand or to gauge seasonal shifts. Thus, while the Mideast is the largest producing region, the bulk of refining takes place in the United States, Europe or Asia.

There have historically been a few exceptions, concentrations of refining capacity that were not proximate to consuming markets. A refining center in the Caribbean, for instance, supplied heavy fuel oil to the U.S. East Coast where it was used for power, heat, and electric generation. As the demand for this heavy fuel oil, or residual fuel oil, waned, so did those dedicated refineries. While the Caribbean refineries, as well as refineries in the Middle East and in Singapore, were built to export product, they are the exception. As such, most refineries meet their “local” demand first, with exports providing a temporary flow for balancing supply and demand.

The largest concentration of refining capacity is in the North America (in fact, the United States), accounting for about one-quarter of the crude oil distillation capacity worldwide. Asia and Europe follow as refining centers. North America (again, the United States) has by far the largest concentration of downstream capacity – the processing units necessary to maximize output of gasoline. The gasoline emphasis of course mirrors the demand barrel and hence refinery output in the different regions, since no other global region uses as much of its oil in the form of gasoline as North America does.

Refinery Profitability and Industry Structure

In general, refining has been significantly less profitable than other industry segments during the 1990’s. Gross refinery margins – the difference between the cost of the input and the price of the output – have been squeezed at the same time that operating costs and the need for additional investment to meet environmental mandates has grown, thus reducing the net margin even further. In addition, much of the investment made during the 1980’s was designed to take advantage of the differential between the dwindling supply of higher quality crude oils and the growing supply of heavier and higher sulfur crudes. When that differential narrowed, however, the financial return of those investments declined. Refining margins peaked in the late 1980’s.

During the 1990’s the role of independent refiners (those without significant production) has grown substantially, largely as the result of refinery purchases from integrated companies (the “majors”) seeking to streamline and realign their positions. Furthermore, the independent refiners, like the majors, are in a period of consolidation; the mergers and acquisitions are having a significant impact on refinery ownership (although not overall refined product supply).

Reference: U.S. Energy Information Act (USEIA); 10/2010.

II. U.S. BASED REFINERIES

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Per the U.S. Energy Information Act (USEIA) website, 141 U.S. refineries are available to refine crude oil.

Barrel per day (BPD) processing capabilities range from 2,000 to 560,640 BPD.

40 of the 141 refineries are located in Texas and Louisiana followed by 20 refineries in California.

Petroleum products manufactured at these facilities are transported by: pipeline, barge, bulk tanker and rail car to terminals located regionally around the refinery.

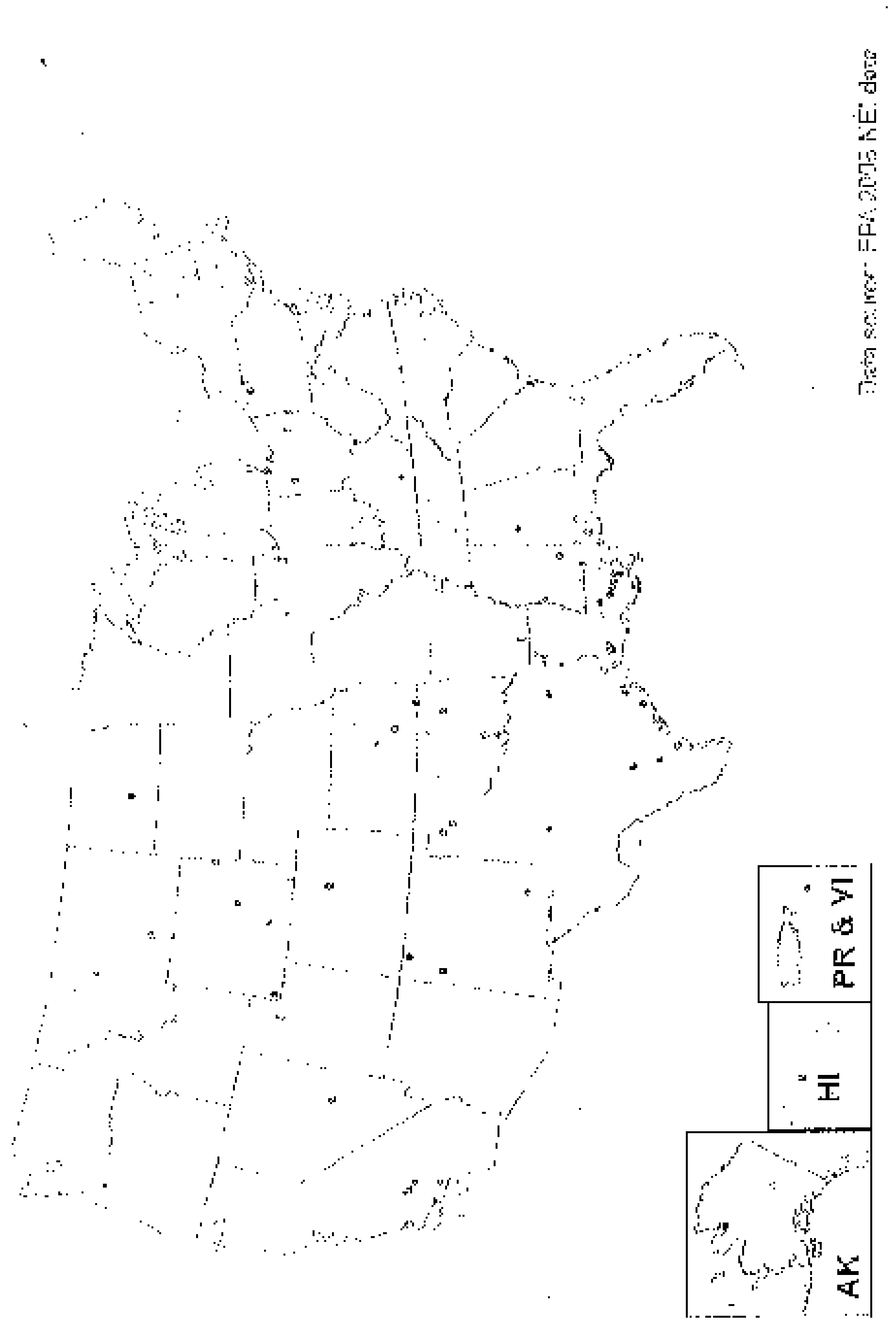
An example of a pipeline distribution map is attached to understand how petroleum products reach your service stations and the end consumer.

NOTE: Please go to:
http://www.theodora.com/pipelines/world_oil_gas_and_products_pipelines.html
to review pipeline information and print maps as needed.

Gasoline is produced to America Society of Testing and Material (ASTM) standards; this finished product is defined as fungible fuel that can be used as a universal fuel. Additive packages are specified by the fuel marketer and are blended into the fungible fuel at the terminal prior to bulk tanker shipment to the service station who serves the end customer (the public).

Reference: U.S. Energy Information Act (USEIA); 10/2010

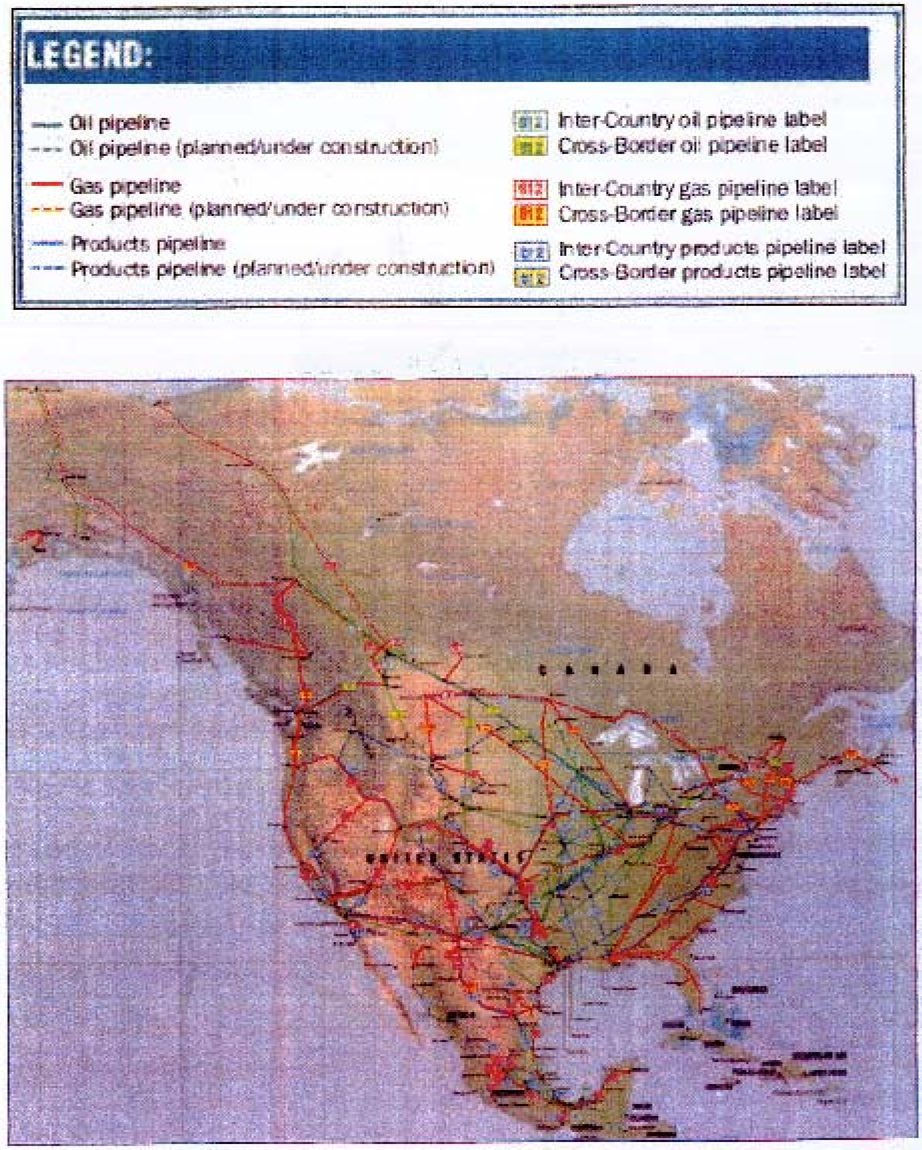
Petroleum Refinery Locations



Data source: EPA 2005 NEI data

NOTE: Please go to:
http://www.theodora.com/pipelines/world_oil_gas_and_products_pipelines.html
to review pipeline information and print maps as needed.

1. **United States Pipelines**
2. **US Gulf of Mexico Pipelines**
3. **Canada Pipelines**
4. **Mexico Pipelines**



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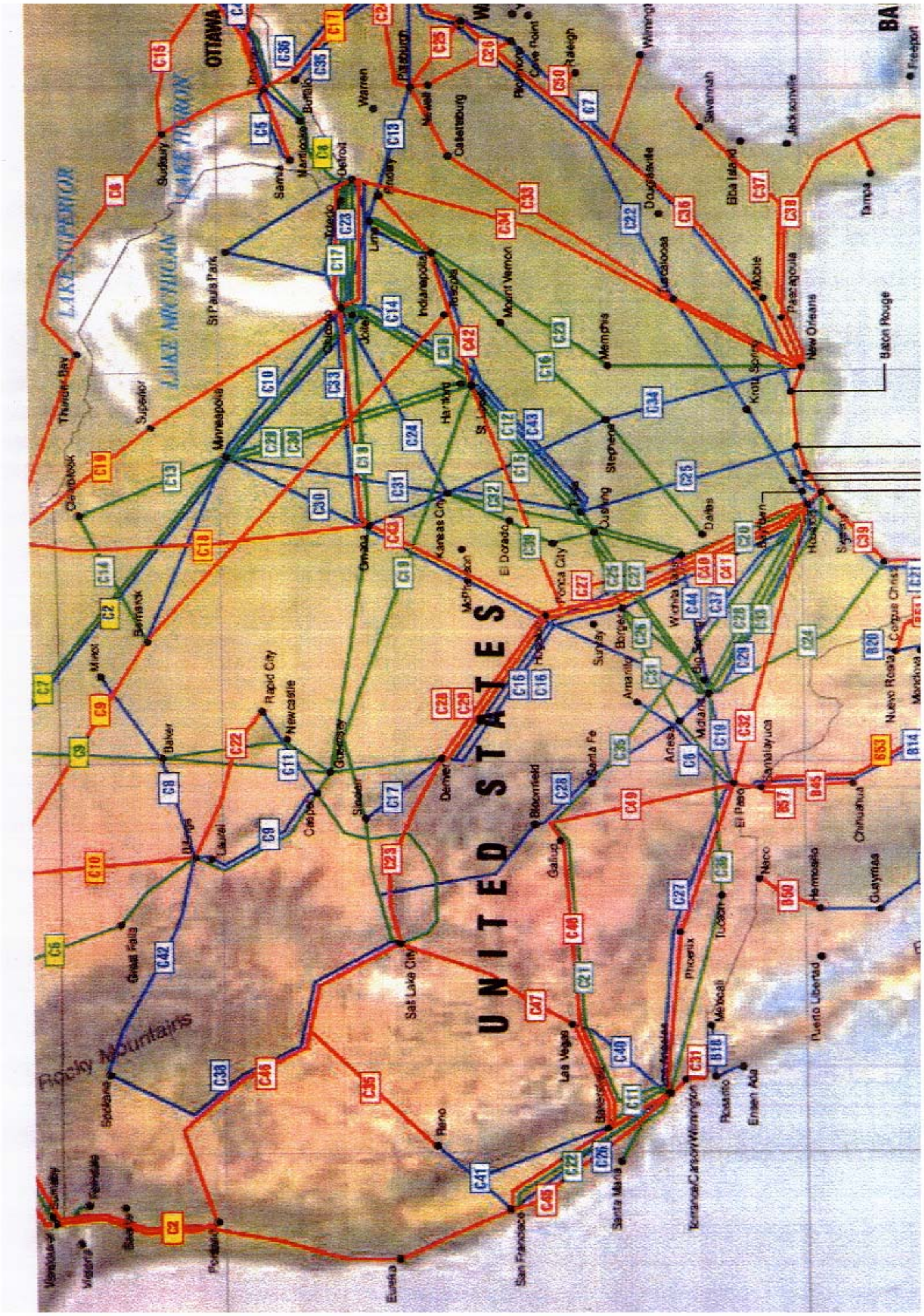

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III. Gasoline Quality – Standards, Specifications, and Additives

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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 drivability, 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 a specific deposit control additive.

Recently more attention has been focused on the environmental requirement 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 important.

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. <u>There is no advantage in using gasoline in a higher AKI than the engine requires to operate knock-free.</u>

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.

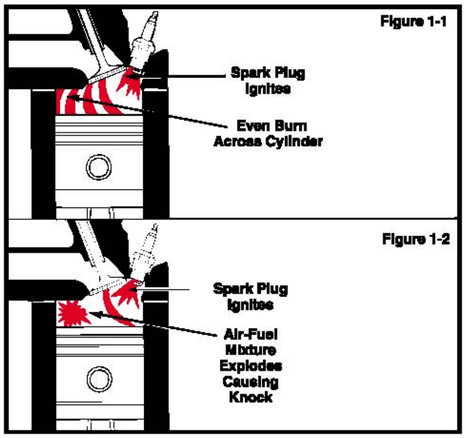
In general, the RON affects low to medium speed knock and engine run-on or dieseling. If the Research Octane Number is too low, the driver could experience low speed knock and engine run-on after the engine is shut off.

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 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.

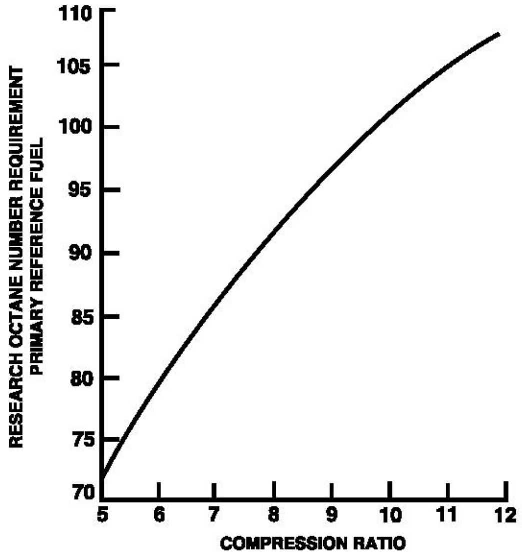
Figure 1-1, 1-2 Proper Combustion vs. Source of Engine Knock



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.

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.

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 requirement when the ignition timing is advanced. The air/fuel ratio also affects 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 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 and has an effect on the areas listed in Table 1-2.

Table 1-2 Effects of Gasoline Volatility on Vehicle Performance

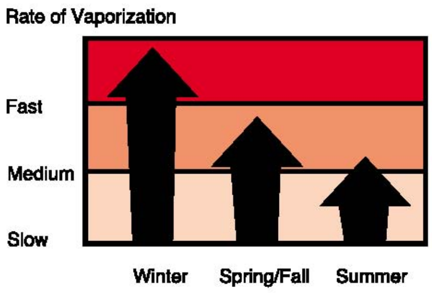
Volatility Too Low	Volatility Too High
Poor cold start	High evaporative emissions/ Canister overload & purge
Poor warm up performance	Hot driveability problems/ vapor lock
Poor cool weather driveability	Fuel economy may deteriorate
Increased deposits -crankcase -combustion chamber -spark plugs	
Unequal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

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

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

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

Figure 1-4
Seasonal Blends Vaporization Characteristics



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

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

There are 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 13 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.

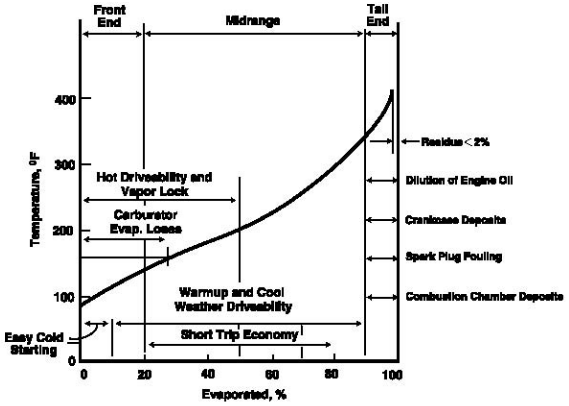
Vapor-Liquid Ratio is a test to determine the temperature required to create a Vapor-Liquid (V/L) ratio of 20. More volatile fuels require lower temperatures to achieve the ratio while less volatile fuels require higher temperatures to create the same ratio. V/L ratio helps in rating a fuel’s tendency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

Reference: Information used under a limited license agreement with the Renewable Fuels Association, Washington, D.C. 6/2011

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

Table 1-3

ASTM D 4814 GASOLINE VOLATILITY REQUIREMENTS

	Distillation Temperatures ° F							
Vapor Pressure/ Distillation Class	**10% Evap. Max.**	**50% Evap.**	**90% Evap. Max.**	**End Point Max.**	**Vapor Pressure psi/Max.**	**Driveability Index Max° F**	**Vapor Lock Protection Class**	**Temp. for Vapor-Liquid Ratio of 20 °F/Min.**
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.

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
Drivability Index Formula

DI = (1.5 x T 10) + (3.0 x T 50) + T 90 + (2.4° F x V% 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 T10 of 122°F, a T50 of 190°F, a T90 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 T50 points that are too low. Where high DI fuels can contribute to poor cold start and warm up performance, if a fuel's T50 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

T10 = 122
T50 = 190
T90 = 360
V% ethanol = 10

DI = (1.5 x 122) + (3 x 190) + 360 + (2.4 x 10)
DI = 183 + 570 + 360 + 24
DI = 1137

<u>Other Fuel Specifications</u>

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

Table 1-6
Gasoline Specifications and Their Importance

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

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.

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.

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

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.

Reference: Information used under a limited license agreement with the Renewable Fuels Association, Washington, D.C. 6/2011

IV. Gasoline Formulations and Ethanol

IV. 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.

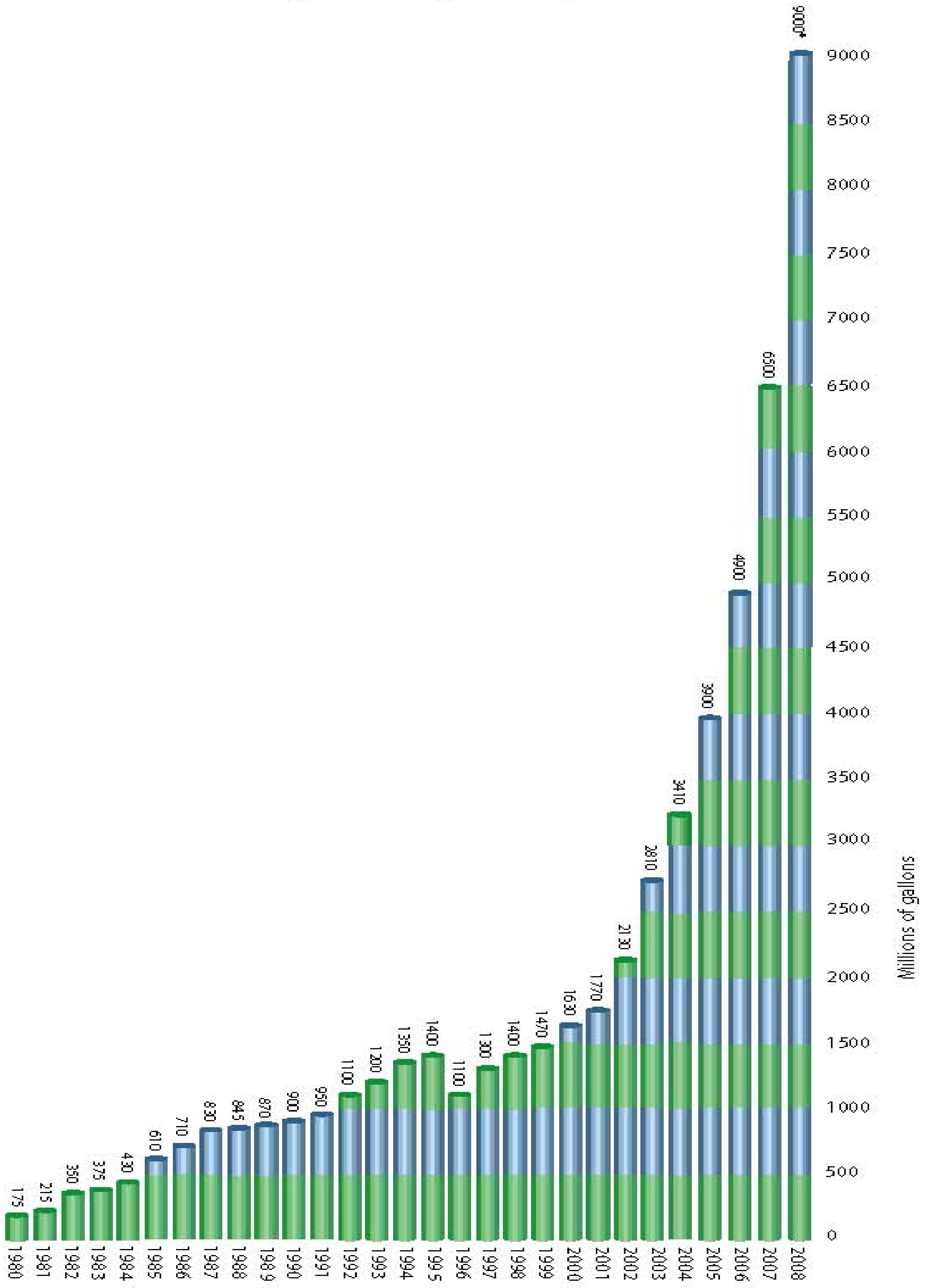
Ethanol

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 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, 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.

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



Source: Renewable Fuels Association, January 2009 *Estimated

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 (CO_2) 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.

Obviously this has created a great deal more interest in ethanol's fuel properties and how it impacts vehicle performance.

Ethanol Properties

Ethanol is the same alcohol used in alcoholic beverages except it is 200 proof (100% alcohol) which has had a few volume percent hydrocarbon added to it so that it cannot be consumed as a beverage.

In the U.S. gasoline typically contains 10v% ethanol and today is referred to as E10, as opposed to gasohol as it was referred to in the 1980s. Other countries such as Brazil blend ethanol at up to 25v%.

Fuel grade ethanol that is blended at up to 10v% in gasoline must meet the specifications set forth in ASTM D 4806 "Standard Specification For Denatured Fuel Ethanol For Blending with Gasoline For Use As Automotive Spark Ignition Engine Fuel". While most components used in gasoline do not have their own ASTM specifications, fuel grade ethanol does. Table 3-1 lists the most important property specifications for fuel grade ethanol.

Table 3-1
ASTM D 4806 Specification Requirements

Ethanol, volume & % min.	92.1
Methanol, volume % max.	0.5
Solvent-washed gum mg/100 ml. max.	5.0
Water content, volume % max.	1.0
Denaturant content, volume % min.	1.96
Volume % max.	5.0
Inorganic Chloride content, mass ppm (mg/L), max.	10 (8)
Acidity (as acetic acid CH^3 COCH), MASS % (MG/L), max.	0.007 (56)
pHe	6.5 to 9.0
Sulfur, mass ppm, max.	30.
Sulfate, mass ppm, max	4
Appearance	Visibly free of suspended or precipitated contaminates (clear and bright).

A minimum ethanol content is specified. The solvent washed gum limit is to control the presence of non-volatile products. Water content is limited to 1.0v% maximum to control water levels in the finished blend. Methanol content is limited because it is corrosive. The denaturant limits are specified to comply with federal laws. Inorganic Chlorides are limited to control corrosion while copper is limited for fuel stability reasons. Acidity and pHe limits ensure the ethanol is not overly corrosive. Sulfur is limited because the gasoline into which the ethanol is blended must meet federal sulfur limits (California has separate specifications to meet their lower gasoline sulfur requirements). Sulfate levels are controlled because excessive amounts could cause fuel system deposits. Finally the appearance requirement is simply a visual check for obvious contaminants such as precipitated contaminants or opaque discolored appearance which could indicate off specification product. ASTM D 4806 also contains a workmanship clause which states, "the product shall be free of any adulterant that may render the material unacceptable for its commonly used applications."

In the early years of use, ethanol was added to gasoline in the transport truck at a terminal located away from the gasoline terminal. For a number of years now, the ethanol blending process has been much more sophisticated. Ethanol is located at the gasoline terminal or refinery loading rack and is metered into the gasoline to achieve an exact blend. At present, blends exceeding 10 v% ethanol are not permitted by law for use in non Flex-Fuel Vehicles.

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

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

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

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.

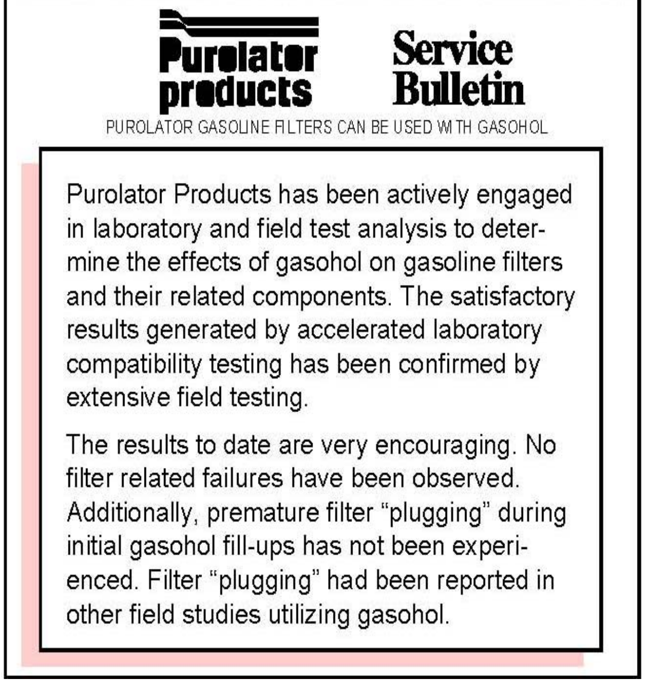
While all auto manufacturers warrant the use of 10v% ethanol blends, their upgrading of fuel systems occurred at different times. In general, 1980 and later model years should not experience problems with 10v% ethanol blends. Fuel systems in 1975 to 1980 model years were upgraded, but not to the same 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).

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.

Fuel System Deposits:

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

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.

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

	Fuel Economy Impact	
FACTOR	Average	Maximum
Ambient temperature drop from 77º to 20º 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%

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 vary 3.4% to 5.0% just based on the energy content of the fuel. Furthermore, comparing the highest energy content summer fuels to lowest energy content winter fuels demonstrates that the variation in energy content is 7.26%. See Table 3-3.

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

	Summer grade btu	**Winter grade but**
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%		

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

The original oxygenated fuel programs, being wintertime 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 lists the btu/gallon (energy content) of denatured ethanol, a typical gasoline and an E10 blend.

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

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. 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.

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 CO_2 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.

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.

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. Consequently, hot driveability problems related to fuel volatility have been largely eliminated.

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.

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.

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 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.

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

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.

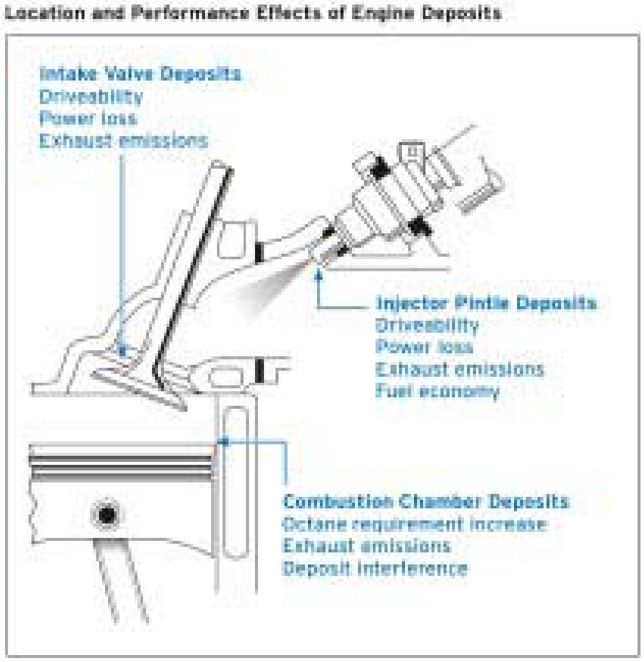
Of course, today, the issue of "sufficient quantities of appropriate detergents" is addressed through the EPA regulations. In addition the automakers and their original equipment manufacturers (OEMs) have redesigned injectors that are less prone to deposit formation. As an example GM introduced the "Multec" 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). The symptoms of IVD are often difficult to distinguish from PFI deposit symptoms. 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.

Figure 4-1
Impact of Deposit Formation in Modern Engines



Courtesy of Chevron Corporation

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 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.

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

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.

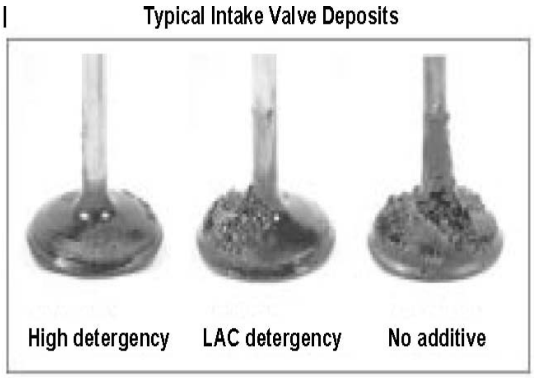
The petroleum, automotive, and additive industries have conducted extensive work to develop standardized industry tests to measure the deposit control characteristics of gasoline and additive treatment packages. In turn, this has enabled the industry to constantly improve its additive packages.

While the EPA regulations require that today's gasolines 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



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.

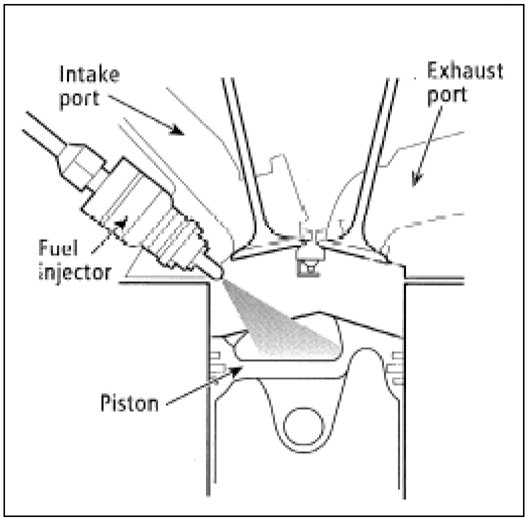
Vehicle owners with IVD sensitive vehicles, and especially those who drive predominantly short driving cycles, may wish to consider using such after-market additives. One aftermarket additive frequently recommended is Chevron's Techron®. Additives employing chemistry similar to Techron® are also available 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.

Figure 4-3
Direct Fuel Injection



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.

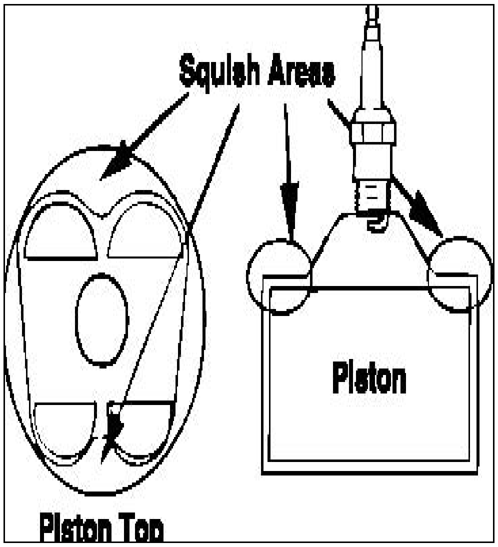
For less severe operation, such as cruising, a stratified charge is more ideal. In this mode a lean fuel mixture is concentrated around the spark plug, which results in improved thermal efficiency. This results in lower fuel consumption and therefore CO^2 emissions compared to a port fuel injected system. Lean fuel conditions can, however, increase NO emissions. In some systems, this may necessitate use of a lean NO emission standards. 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).

Figure 4-4
Combustion Chamber Deposit
Interference Areas



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).

Figure 4-5
Alcohol Detection Test

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 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 charges 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.

Reference: Information used under a limited license agreement with the Renewable Fuels Association, Washington, D.C. 6/2011