CHAPTER 11

GASOLINE AND ALTERNATIVE FUELS

OBJECTIVES

After studying Chapter 11, the reader will be able to:

1. Describe how the proper grade of gasoline affects engine performance.
2. List gasoline purchasing hints.
3. Discuss how volatility affects driveability.
4. Explain how oxygenated fuels can reduce CO exhaust emissions.
5. Discuss the advantages and disadvantages of various alternative fuels.

KEY TERMS

AFV (p. 143)
Air–Fuel Ratio (p. 138)
AKI (p. 134)
Anhydrous Ethanol (p. 143)
API Gravity (p. 151)
ASTM (p. 130)
B20 (p. 153)
Biodiesel (p. 153)
Biomass (p. 147)
BTU (p. 137)
Catalytic Cracking (p. 129)
Cellulose Ethanol (p. 142)
Cellulosic Biomass (p. 142)
Cetane Rating (p. 151)
CNG (p. 148)
Cracking (p. 129)
CTL (p. 155)
Detonation (p. 132)
DI (p. 131)
Diesohol (p. 154)
Distillation (p. 129)
Distillation Curve (p. 131)
E10 (p. 136)
E85 (p. 143)
E-diesel (p. 154)
ETBE (p. 136)
Ethanol (p. 136)
Ethyl Alcohol (p. 136)
FFV (p. 143)
Fischer-Tropsch Diesel (p. 155)
Flex Fuel (p. 143)
FTD (p. 155)
Fuel Compensation Sensor (p. 144)
Fuel Composition Sensor (p. 144)
Gasoline (p. 129)
Grain Alcohol (p. 142)
GTL (p. 155)
Hydrocracking (p. 129)
LPG (p. 148)
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MTG (p. 156)
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Organic (p. 137)
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Propane (p. 148)
RFG (p. 139)
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Spark Knock (p. 132)
Stoichiometric (p. 138)
Switchgrass (p. 145)
Syn-Gas (p. 147)
Synthetic Fuel (p. 155)
SVO (p. 154)
TAME (p. 136)
TEL (p. 132)
UCG (p. 156)
UCO (p. 154)
ULSD (p. 153)
Vapor Lock (p. 130)
Variable Fuel Sensor (p. 144)
V-FFV (p. 144)
Volatility (p. 129)
Wood Alcohol (p. 136)
WVO (p. 154)
WWFC (p. 140)

The quality of the fuel any engine uses is important to its proper operation and long life. If the fuel is not right for the air temperature or if the tendency of the fuel to evaporate is incorrect, severe driveability problems can result. An engine burns about 15 pounds of air for every pound of gasoline.

AUTOMOTIVE FUEL REFINING

As it comes out of the ground, **petroleum** (meaning "rock oil") crude can be as thin and light colored as apple cider or as thick and black as melted tar. Thin crude oil has a high American Petroleum Institute (API) gravity, and therefore is called *high-gravity* crude, and thick crude oil is called *low-gravity* crude. High-gravity-type crude contains more natural gasoline and its lower sulfur and nitrogen content makes it easier to refine.

NOTE: Low-sulfur crude oil is also known as "sweet" crude and high-sulfur crude oil is also known as "sour crude."

Processes

Refining is a complex combination of interdependent processing units, and it all starts with the simple physical separation process called **distillation.**

Distillation

In the late 1800s, crude was separated into different products by boiling. Distillation works because crude is composed of hydrocarbons with a wide range of molecular weights, and therefore a broad range of boiling points. Each product was assigned a temperature range and the product was obtained by condensing the vapor that boiled off in this range at atmospheric pressure (atmospheric distillation). The earliest crude stills were simple pot stills consisting of a container where crude was heated and a condenser to condense the vapor. Later, distillation became a continuous process with a pump to provide crude flow, a furnace to heat the crude, and a distillation column to separate the different boiling cuts.

In a distillation column, the vapor of the lowest-boiling hydrocarbons, propane and butane, rises to the top. The straight-run gasoline (also called naphtha), kerosene, and diesel fuel cuts are drawn off at successively lower positions in the column.

Cracking

The discovery that hydrocarbons with higher boiling points could be broken down (cracked) into lower-boiling hydrocarbons by subjecting them to very high temperatures offered a way to correct the mismatch between supply and demand. This process, thermal **cracking,** was used to increase gasoline production starting in 1913. It is the nature of thermal cracking to make a lot of olefins, which have higher octane numbers but may cause engine deposits. By today's standards, the quality and performance of this early cracked gasoline was low, but it was sufficient for the engines of the day.

Eventually heat was supplemented by a catalyst, transforming thermal cracking into **catalytic cracking.** A catalyst is a material that speeds up or otherwise facilitates a chemical reaction without undergoing a permanent chemical change itself. Catalytic cracking produces gasoline of higher quality than thermal cracking.

Hydrocracking is similar to catalytic cracking in that it uses a catalyst, but the catalyst is in a hydrogen atmosphere. Hydrocracking can break down hydrocarbons that are resistant to catalytic cracking alone. It more commonly is used to produce diesel fuel rather than gasoline.

Other types of refining processes include:

- Reforming
- Alkylation
- Isomerization
- Hydrotreating
- Desulfurization

See Figure 11-1.

Shipping

The gasoline is transported to regional storage facilities by tank railway car or by pipeline. In the pipeline method, all gasoline from many refiners is often sent through the same pipeline and can become mixed. All gasoline is said to be *miscible*, meaning that it is capable of being mixed because each grade is created to specification so there is no reason to keep the different gasoline brands separated except for grade. Regular grade, midgrade, and premium grades are separated in the pipeline and the additives are added at the regional storage facilities and then shipped by truck to individual gas stations.

GASOLINE

Gasoline is a term used to describe a complex mixture of various hydrocarbons refined from crude petroleum oil for use as a fuel in spark-ignition engines. Most gasoline is "blended" to meet the needs of the local climates and altitudes.

VOLATILITY

Volatility describes how easily the gasoline evaporates (forms a vapor). The definition of volatility assumes that the vapors

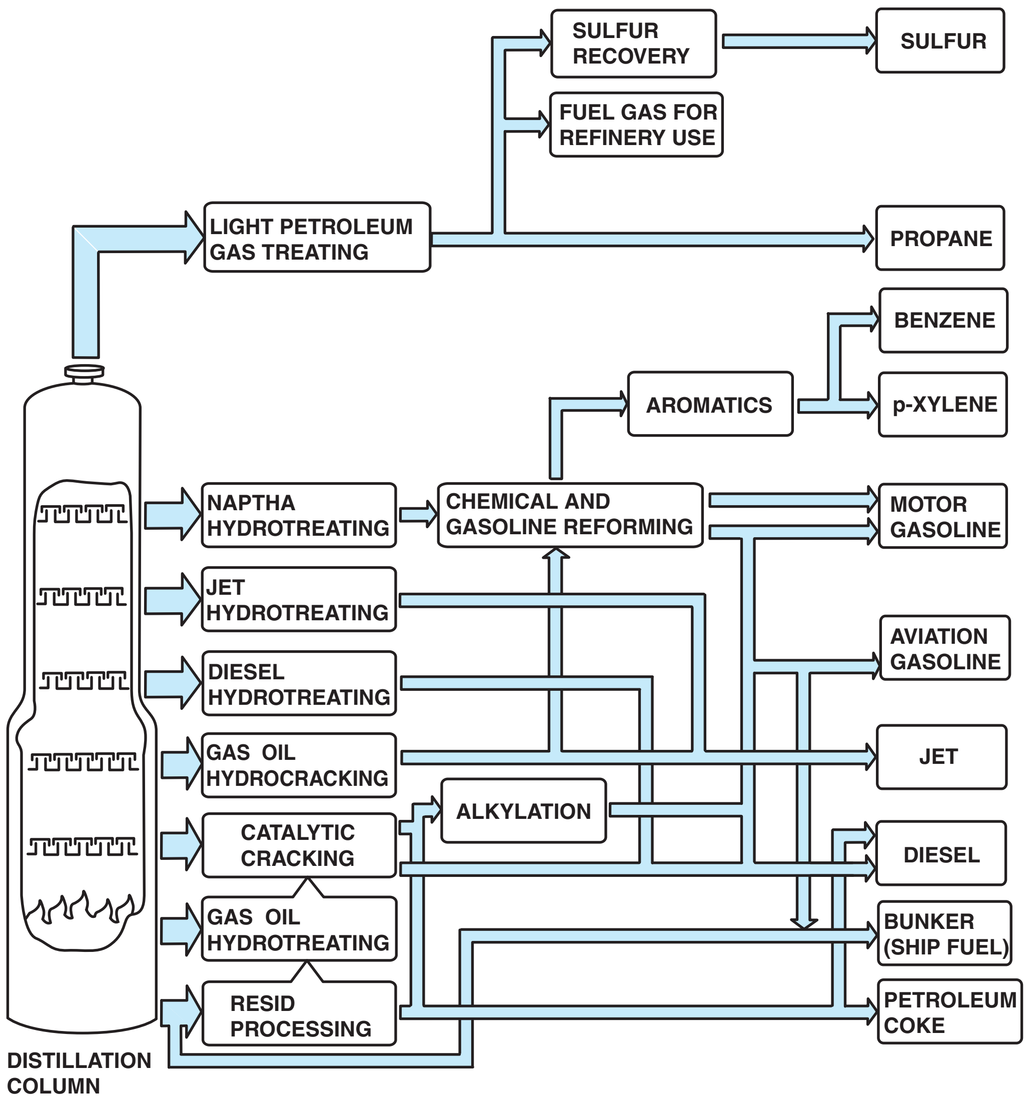

FIGURE 11-1 The crude oil refining process showing most of the major steps and processes.

will remain in the fuel tank or fuel line and will cause a certain pressure based on the temperature of the fuel.

Winter Blend

Reid vapor pressure (RVP) is the pressure of the vapor above the fuel when the fuel is at 100°F (38°C). Increased vapor pressure permits the engine to start in cold weather. Gasoline without air will not burn. Gasoline must be vaporized (mixed with air) to burn in an engine. Cold temperatures reduce the normal vaporization of gasoline; therefore, winter-blended gasoline is specially formulated to vaporize at lower temperatures for proper starting and driveability at low ambient temperatures. The **American Society for Testing and Materials (ASTM)** standards for winter-blend gasoline allow volatility of up to 15 pounds per square inch (PSI) RVP.

Summer Blend

At warm ambient temperatures, gasoline vaporizes easily. However, the fuel system (fuel pump, carburetor, fuel-injector nozzles, etc.) is designed to operate with liquid gasoline. The volatility of summer-grade gasoline should be about 7.0 PSI RVP. According to ASTM standards, the maximum RVP should be 10.5 PSI for summer-blend gasoline.

Volatility Problems

At higher temperatures, liquid gasoline can easily vaporize, which can cause **vapor lock.** Vapor lock is a *lean* condition caused by vaporized fuel in the fuel system. This vaporized fuel takes up space normally occupied by liquid fuel. Vapor

FREQUENTLY ASKED QUESTION

WHAT IS A CALIFORNIA GAS CAN?

When researching for ways to reduce hydrocarbon emissions in California, it was discovered that leakage from small gasoline containers used to refill small lawnmowers and other power equipment was a major source of unburned gasoline entering the atmosphere. As a result of this discovery, a new design for a gas can (container) was developed that is kept closed by a spring and uses O-rings to seal the opening. To use this container, the nozzle release lever is held against the side of the fuel opening and, when depressed, allows air to enter the container and fuel to flow. The flow of fuel stops automatically when the tank is full, eliminating any spillage. See Figure 11-2.

FIGURE 11-2 A gas can that meets the California Resources Board (CARB) approval uses a spring-loaded sealed nozzle that eliminates gasoline spillage and leaks into the atmosphere.

lock is caused by bubbles that form in the fuel, preventing proper operation of the fuel-injection system.

Bubbles in the fuel can be caused by heat or by sharp bends in the fuel system. Heat causes some fuel to evaporate, thereby causing bubbles. Sharp bends cause the fuel to be restricted at the bend. When the fuel flows past the bend, the fuel can expand to fill the space after the bend. This expansion drops the pressure, and bubbles form in the fuel lines. When the fuel is full of bubbles, the engine is not being supplied with enough fuel and the engine runs lean. A lean engine will stumble during acceleration, will run rough, and may stall. Warm weather and alcohol-blended fuels both tend to increase vapor lock and engine performance problems.

If winter-blend gasoline (or high-RVP fuel) is used in an engine during warm weather, the following problems may occur:

1. Rough idle
2. Stalling
3. Hesitation on acceleration
4. Surging

The RVP can be tested using the test kit shown in Figure 11-3.

FIGURE 11-3 A gasoline testing kit. Included is an insulated container where water at 100°F is used to heat a container holding a small sample of gasoline. The reading on the pressure gauge is the Reid vapor pressure (RVP).

DISTILLATION CURVE

Besides Reid vapor pressure, another method of classifying gasoline volatility is the **distillation curve.** A curve on a graph is created by plotting the temperature at which the various percentage of the fuel evaporates. A typical distillation curve is shown in Figure 11-4.

DRIVEABILITY INDEX

A distillation curve shows how much of a gasoline evaporates at what temperature range. To predict cold-weather driveability, an index was created called the **driveability index,** also called the **distillation index,** and abbreviated **DI.**

The DI was developed using the temperature for the evaporated percentage of 10% (labeled T10), 50% (labeled T50), and 90% (labeled T90). The formula for DI is:

$$DI = 1.5 \times T10 + 3 \times T50 + T90$$

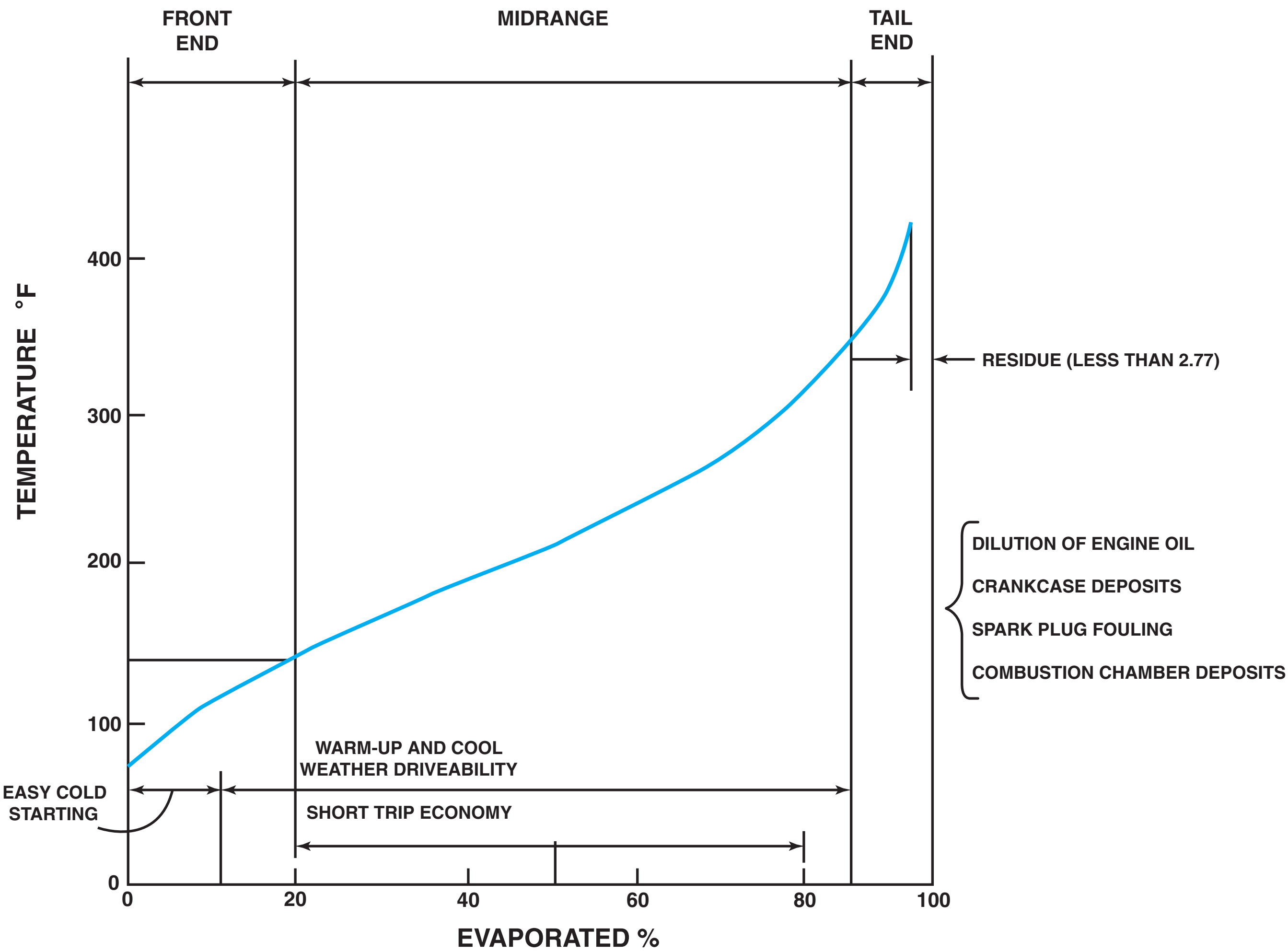

FIGURE 11-4 A typical distillation curve. Heavier molecules evaporate at higher temperatures and contain more heat energy for power, whereas the lighter molecules evaporate easier for starting.

The total DI is a temperature and usually ranges from 1,000° to 1,200°F. The lower values of DI generally result in good cold-start and warm-up performance. A high DI number is less volatile than a low DI number.

NOTE: Most premium-grade gasoline has a higher (worse) DI than regular or midgrade gasoline, which could cause poor cold-weather driveability. Vehicles designed to operate on premium-grade gasoline are programmed to handle the higher DI, but engines designed to operate on regular-grade gasoline may not be able to provide acceptable cold-weather driveability.

NORMAL AND ABNORMAL COMBUSTION

The **octane rating** of gasoline is the measure of its antiknock properties. *Engine knock* (also called **detonation, spark knock,** or **ping**) is a metallic noise an engine makes, usually during acceleration, resulting from abnormal or uncontrolled combustion inside the cylinder.

Normal combustion occurs smoothly and progresses across the combustion chamber from the point of ignition. See Figure 11-5.

Normal flame-front combustion travels between 45 and 90 mph (72 and 145 km/h). The speed of the flame front depends on air–fuel ratio, combustion chamber design (determining amount of turbulence), and temperature.

During periods of spark knock (detonation), the combustion speed increases by up to 10 times to near the speed of sound. The increased combustion speed also causes increased temperatures and pressures, which can damage pistons, gaskets, and cylinder heads. See Figure 11-6.

One of the first additives used in gasoline was **tetraethyl lead (TEL).** TEL was added to gasoline in the early 1920s to reduce the tendency to knock. It was often called ethyl or high-test gasoline.

FREQUENTLY ASKED QUESTION

WHY DO I GET LOWER GAS MILEAGE IN THE WINTER?

Several factors cause the engine to use more fuel in the winter than in the summer, including:

- Gasoline that is blended for use in cold climates is designed for ease of starting and contains fewer heavy molecules, which contribute to fuel economy. The heat content of winter gasoline is lower than summer-blended gasoline.
- In cold temperatures, all lubricants are stiff, causing more resistance. These lubricants include the engine oil, as well as the transmission and differential gear lubricants.
- Heat from the engine is radiated into the outside air more rapidly when the temperature is cold, resulting in longer run time until the engine has reached normal operating temperature.
- Road conditions, such as ice and snow, can cause tire slippage or additional drag on the vehicle.

TECH TIP

THE SNIFF TEST

Problems can occur with stale gasoline from which the lighter parts of the gasoline have evaporated. Stale gasoline usually results in a no-start situation. If stale gasoline is suspected, sniff it. If it smells rancid, replace it with fresh gasoline.

NOTE: If storing a vehicle, boat, or lawnmower over the winter, put some gasoline stabilizer into the gasoline to reduce the evaporation and separation that can occur during storage. Gasoline stabilizer is frequently available at lawnmower repair shops or marinas.

Some experts recommend that a diesel fuel additive be used to kill bacteria and fungi growth that occurs in fuels when moisture is present. To kill algae and stop bacterial growth, use from 0.25 to 0.50 fl. oz. of additive in each 20 gallons. While algae growth is usually associated with diesel fuel when water collects at the bottom of the tank, gasoline tanks can still be a source of algae, especially when vehicles are stored for long periods of time, usually over 90 days.

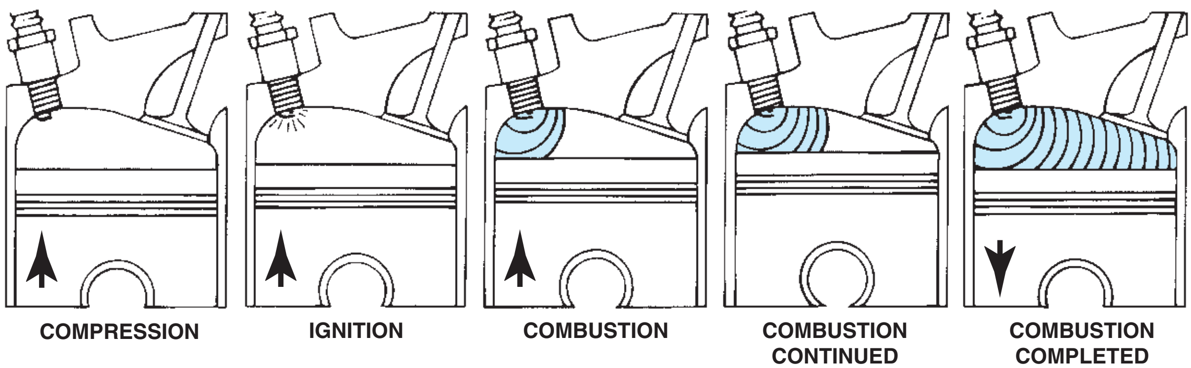

FIGURE 11-5 Normal combustion is a smooth, controlled burning of the air–fuel mixture.

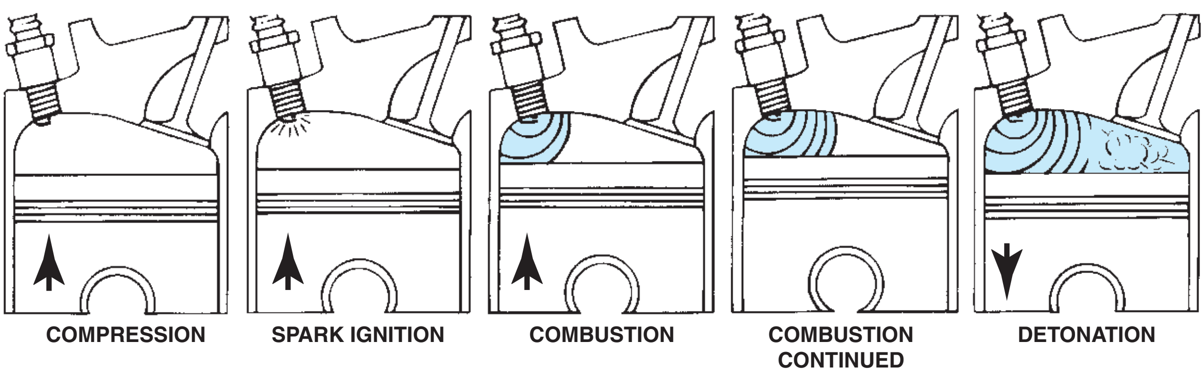

FIGURE 11-6 Detonation is a secondary ignition of the air–fuel mixture. It is also called spark knock or pinging.

OCTANE RATING

The antiknock standard or basis of comparison was the knock-resistant hydrocarbon isooctane, chemically called trimethylpentane (C_8H_{18}), also known as 2-2-4 trimethylpentane. If a gasoline tested had the exact same antiknock characteristics as isooctane, it was rated as 100-octane gasoline. If the gasoline tested had only 85% of the antiknock properties of isooctane, it was rated as 85 octane. Remember, octane rating is only a comparison test.

The two basic methods used to rate gasoline for antiknock properties (octane rating) are the *research method* and the *motor method*. Each uses a model of the special cooperative fuel research (CFR) single-cylinder engine. The research method and the motor method vary as to temperature of air, spark advance, and other parameters. The research method typically results in readings that are 6 to 10 points higher than those of the motor method. For example, a fuel with a research octane number (RON) of 93 might have a motor octane number (MON) of 85.

The octane rating posted on pumps in the United States is the average of the two methods and is referred to as $(R + M) \div 2$, meaning that, for the fuel used in the previous example, the rating posted on the pumps would be

$$\frac{RON + MON}{2} = \frac{93 + 85}{2} = 89$$

The pump octane is called the **antiknock index (AKI).**

GASOLINE GRADES AND OCTANE NUMBER

The posted octane rating on gasoline pumps is the rating achieved by the average of the research and the motor methods. See Figure 11-7.

FREQUENTLY ASKED QUESTION

WHAT GRADE OF GASOLINE DOES THE EPA USE WHEN TESTING ENGINES?

Due to the various grades and additives used in commercial fuel, the government (EPA) uses a liquid called indolene. Indolene has a research octane number of 96.5 and a motor method octane rating of 88, which results in an $R + M \div 2$ rating of 92.25.

FIGURE 11-7 A typical fuel pump showing regular (87 octane), midgrade (89 octane), and premium (92 octane). These ratings can vary with brand as well as in different parts of the country, especially in high-altitude areas where the ratings are lower.

Except in high-altitude areas, the grades and octane ratings are as follows:

Grades	*Octane Rating*
Regular	87
Midgrade (also called Plus)	89
Premium	91 or higher

TECH TIP

HORSEPOWER AND FUEL FLOW

To produce 1 hp, the engine must be supplied with 0.50 lb of fuel per hour (lb/hr). Fuel injectors are rated in pounds per hour. For example, a V-8 engine equipped with 25 lb/hr fuel injectors could produce 50 hp per cylinder (per injector) or 400 hp. Even if the cylinder head or block is modified to produce more horsepower, the limiting factor may be the injector flow rate.

The following are flow rates and resulting horsepower for a V-8 engine:

30 lb/hr: 60 hp per cylinder or 480 hp
35 lb/hr: 70 hp per cylinder or 560 hp
40 lb/hr: 80 hp per cylinder or 640 hp

Of course, injector flow rate is only one of many variables that affect power output. Installing larger injectors without other major engine modification could decrease engine output and drastically increase exhaust emissions.

REAL WORLD FIX

THE STALLING ACURA

On a warm day in March, a customer walked into an automotive repair shop and asked for help. The car was parked on the street just outside the shop. A service technician accompanied the owner to check out the situation. The owner complained that the engine would start, then immediately stall. The engine would again start, and then stall during another attempt.

The service technician slid into the driver's seat and turned the ignition key. When the engine started, the technician depressed the accelerator slightly and the engine continued to run without any apparent problem. The car owner had never depressed the accelerator pedal and had never had any previous engine trouble.

The technician suspected winter-grade (high-RVP) gasoline was the problem. The owner replied that the present tank of fuel had been purchased during the last week in February. The technician explained that the uncommonly warm weather caused the fuel to vaporize in the fuel rail. Enough condensed fuel was available to start the engine, but the fuel injectors were designed to handle liquid fuel—not vapor—so the engine stalled.

The technician was probably lucky because by the third start enough of the remaining vapor had been drawn into the engine so that all that remained was liquid gasoline.

OCTANE IMPROVERS

When gasoline companies, under federal EPA regulations, removed tetraethyl lead from gasoline, other methods were developed to help maintain the antiknock properties of gasoline. Octane improvers (enhancers) can be grouped into three broad categories:

1. Aromatic hydrocarbons (hydrocarbons containing the benzene ring) such as xylene and toluene
2. Alcohols such as ethanol (ethyl alcohol), methanol (methyl alcohol), and tertiary butyl alcohol (TBA)
3. Metallic compounds such as methylcyclopentadienyl manganese tricarbonyl (MMT)

NOTE: MMT has been proven to be harmful to catalytic converters and can cause spark plug fouling. However, MMT is currently one of the active ingredients commonly found in octane improvers available to the public and in some gasoline sold in Canada. If an octane boost additive has been used that contains MMT, the spark plug porcelain will be rust colored around the tip.

FREQUENTLY ASKED QUESTION

CAN REGULAR-GRADE GASOLINE BE USED IF PREMIUM IS THE RECOMMENDED GRADE?

Yes. It is usually possible to use regular or midgrade (plus) grade gasoline in most newer vehicles without danger of damage to the engine. Most vehicles built since the 1990s are equipped with at least one knock sensor. If a lower octane gasoline than specified is used, the engine ignition timing setting will usually cause the engine to spark knock, also called detonation or ping. This spark knock is detected by the knock sensor(s), which sends a signal to the computer. The computer then retards the ignition timing until the spark knock stops.

NOTE: Some scan tools will show the "estimated octane rating" of the fuel being used, which is based on knock sensor activity.

As a result of this spark timing retardation, the engine torque is reduced. While this reduction in power is seldom noticed, it will reduce fuel economy, often by 4 to 5 miles per gallon. If premium gasoline is then used, the PCM will gradually permit the engine to operate at the more advanced ignition timing setting. Therefore, it may take several tanks of premium gasoline to restore normal fuel economy. For best overall performance, use the grade of gasoline recommended by the vehicle manufacturer.

Propane and butane, which are volatile by-products of the refinery process, are also often added to gasoline as octane improvers. The increase in volatility caused by the added propane and butane often leads to hot-weather driveability problems.

OXYGENATED FUELS

Oxygenated fuels contain oxygen in the molecule of the fuel itself. Examples of oxygenated fuels include methanol, ethanol, methyl tertiary butyl ether (MTBE), tertiary-amyl methyl ether (TAME), and ethyl tertiary butyl ether (ETBE).

Oxygenated fuels are commonly used in high-altitude areas to reduce carbon monoxide (CO) emissions. The extra oxygen in the fuel itself is used to convert harmful CO into carbon dioxide (CO_2). The extra oxygen in the fuel helps ensure that there is enough oxygen to convert all the CO into CO_2 during the combustion process in the engine or catalytic converter.

Methyl Tertiary Butyl Ether (MTBE)

MTBE is manufactured by means of the chemical reaction of methanol and isobutylene. Unlike methanol, MTBE does not increase the volatility of the fuel, and is not as sensitive to water as are other alcohols. The maximum allowable volume level, according to the EPA, is 15% but is currently being phased out due to health concerns, as well as MTBE contamination of drinking water if spilled from storage tanks.

Tertiary-Amyl Methyl Ether

Tertiary-amyl methyl ether **(TAME)** is an oxygenate added to gasoline and is flammable and can form explosive mixtures with air. It is slightly soluble in water, very soluble in ethers and alcohol, and soluble in most organic solvents including hydrocarbons. TAME is an ether, which contains an oxygen atom bonded to two carbon atoms.

Ethyl Tertiary Butyl Ether

ETBE is derived from ethanol. The maximum allowable volume level is 17.2%. The use of ETBE is the cause of much of the odor from the exhaust of vehicles using reformulated gasoline.

Ethanol

Ethyl alcohol is drinkable alcohol and is usually made from grain. Adding 10% ethanol (ethyl alcohol or grain alcohol) increases the $(R + M) \div 2$ octane rating by three points. The alcohol added to the base gasoline, however, also raises the volatility of the fuel about 0.5 PSI. Most automobile manufacturers permit up to 10% ethanol if driveability problems are not experienced. The oxygen content of a 10% blend of **ethanol** in gasoline, called **E10,** is 3.5% oxygen by weight. See Figure 11-8.

Methanol

Methyl alcohol is made from wood **(wood alcohol),** natural gas, or coal. Methanol is poisonous if ingested and tends to be more harmful to the materials in the fuel system and to separate when combined with gasoline unless used with a co-solvent. A co-solvent is another substance (usually another alcohol) that is soluble in both methanol and gasoline and is used to reduce the tendency of the liquids to separate.

Methanol can damage fuel system parts. Methanol is corrosive to lead (used as a coating of fuel tanks), aluminum, magnesium, and some plastics and rubber. Methanol can also cause rubber products (elastomers) to swell and soften. Methanol contains oxygen and gasoline containing 5% methanol would have an oxygen content of 2.5% by weight.

FIGURE 11-8 This fuel pump indicates that the gasoline is blended with 10% ethanol (ethyl alcohol) and can be used in any gasoline vehicle. E85 contains 85% ethanol and can only be used in vehicles specifically designed to use it.

CAUTION: All alcohols absorb water, and the alcohol–water mixture can separate from the gasoline and sink to the bottom of the fuel tank. This process is called *phase separation.* To help avoid engine performance problems, try to keep at least a quarter tank of fuel at all times, especially during seasons when there is a wide temperature span between daytime highs and nighttime lows. These conditions can cause moisture to accumulate in the fuel tank as a result of condensation of the moisture in the air. Keeping the fuel tank full reduces the amount of air and moisture in the tank. See Figure 11-9.

ALCOHOL ADDITIVES—ADVANTAGES AND DISADVANTAGES

The advantages and disadvantages of using alcohol as an additive to gasoline can be summarized as follows:

Advantages

1. Alcohol absorbs moisture in the fuel tank.
2. Ten percent alcohol added to gasoline raises the octane rating, $(R + M) \div 2$, by three points.
3. Alcohol cleans the fuel system.
4. Alcohol reduces CO emissions because it contains oxygen.

Disadvantages

1. The use of alcohol can result in the clogging of fuel filters with dirt and other debris cleaned from the fuel tank, pump, and lines.
2. Alcohol raises the volatility of fuel about 0.5 PSI; this can cause hot-weather driveability problems.

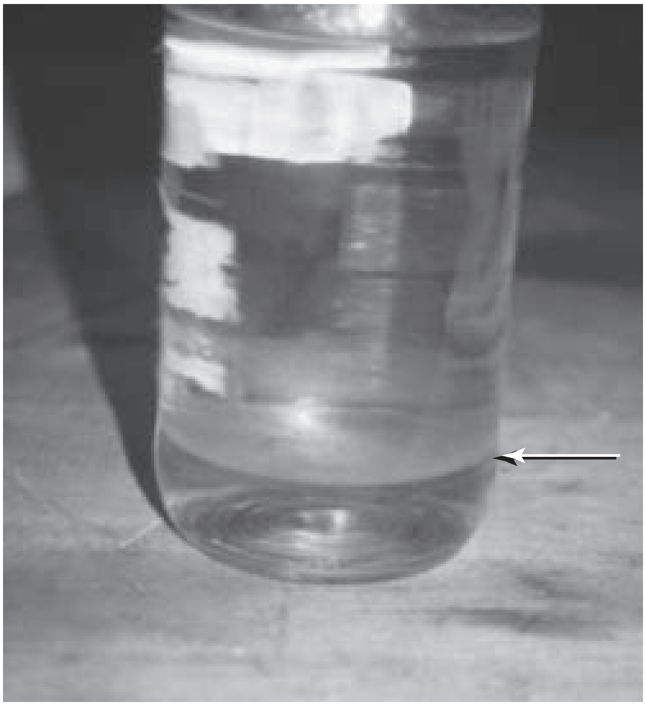

FIGURE 11-9 A container with gasoline containing alcohol. Notice the separation line where the alcohol–water mixture separated from the gasoline and sank to the bottom.

3. Alcohol reduces the heat content of the resulting fuel mixture (it has about one-half of the energy content of gasoline)—60,000 to 75,000 **British thermal units (BTUs)** per gallon for alcohol versus about 130,000 BTUs per gallon for gasoline.
4. Alcohol absorbs water and then separates from the gasoline, especially as temperature drops. Separated alcohol and water on the bottom of the tank can cause hard starting during cold weather. Alcohol does not vaporize easily at low temperatures.

FREQUENTLY ASKED QUESTION

IS WATER HEAVIER THAN GASOLINE?

Yes. Water weighs about 7 pounds per gallon whereas gasoline weighs about 6 pounds per gallon. The density as measured by specific gravity includes:

Water = 1.000 (the baseline for specific gravity)
Gasoline = 0.730 to 0.760

This means that any water that gets into the fuel tank will sink to the bottom.

TESTING GASOLINE FOR ALCOHOL CONTENT

Take the following steps when testing gasoline for alcohol content.

1. Pour suspect gasoline into a small clean beaker or glass container.

CAUTION: DO NOT SMOKE OR RUN THE TEST AROUND SOURCES OF IGNITION!

2. Carefully fill the graduated cylinder to the 10-mL mark.
3. Add 2 mL of water to the graduated cylinder by counting the number of drops from an eyedropper. (Before performing the test, the eyedropper must be calibrated to determine how many drops equal 2.0 mL.)
4. Put the stopper in the cylinder and shake vigorously for 1 minute. Relieve built-up pressure by occasionally removing the stopper. Alcohol dissolves in water and will drop to the bottom of the cylinder.
5. Place the cylinder on a flat surface and let it stand for 2 minutes.
6. Take a reading near the bottom of the cylinder at the boundary between the two liquids.
7. For percent of alcohol in gasoline, subtract 2 from the reading and multiply by 10. For example,

The reading is 3.1 mL: $3.1 - 2 = 1.1 \times 10 =$ 11% alcohol
The reading is 2.0 mL: $2 - 2 = 0 \times 10 =$ 0% alcohol (no alcohol)

If the increase in volume is 0.2% or less, it may be assumed that the test gasoline contains no alcohol. Alcohol content can also be checked using an electronic tester. See the step-by-step sequence at the end of the chapter.

COMBUSTION CHEMISTRY

Internal combustion engines burn an organic fuel to produce power. The term **organic** refers to a product (gasoline) from a source that originally was alive. Because crude oil originally came from living plants and animals, all products of petroleum are considered organic fuels and are composed primarily of hydrogen (H) and carbon (C).

The combustion process involves the chemical combination of oxygen (O_2) from the air (about 21% of the atmosphere) with the hydrogen and carbon from the fuel. In a gasoline engine, a spark starts the combustion process, which takes about 3 ms (0.003 sec) to be completed inside the cylinder of an engine. The chemical reaction that takes place can be summarized as follows: hydrogen (H) plus carbon (C) plus oxygen (O_2) plus nitrogen (N) plus spark equals heat plus

FREQUENTLY ASKED QUESTION

HOW DOES ALCOHOL CONTENT IN THE GASOLINE AFFECT ENGINE OPERATION?

In most cases, the use of gasoline containing 10% or less of ethanol (ethyl alcohol) has little or no effect on engine operation. However, because the addition of 10% ethanol raises the volatility of the fuel slightly, occasional rough idle or stalling may be noticed, especially during warm weather. The rough idle and stalling may also be noticeable after the engine is started, driven, then stopped for a short time. Engine heat can vaporize the alcohol-enhanced fuel, causing bubbles to form in the fuel system. These bubbles in the fuel prevent the proper operation of the fuel injection system and result in a hesitation during acceleration, rough idle, or in severe cases repeated stalling until all the bubbles have been forced through the fuel system, replaced by cooler fuel from the fuel tank.

water (H_2O) plus carbon monoxide (CO) (if incomplete combustion) plus carbon dioxide (CO_2) plus hydrocarbons (HC) plus oxides of nitrogen (NO_X) plus many other chemicals.

AIR–FUEL RATIOS

Fuel burns best when the intake system turns it into a fine spray and mixes it with air before sending it into the cylinders. In fuel-injected engines, the fuel becomes a spray and mixes with the air in the intake manifold. There is a direct relationship between engine airflow and fuel requirements; this is called the **air–fuel ratio.**

The air–fuel ratio is the proportion by weight of air and gasoline that the injection system mixes as needed for engine combustion. The mixtures, with which an engine can operate without stalling, range from 8 to 1 to 18.5 to 1. See Figure 11-10.

These ratios are usually stated by weight, such as:

- 8 parts of air by weight combined with 1 part of gasoline by weight (8:1), which is the richest mixture that an engine can tolerate and still fire reliably.
- 18.5 parts of air mixed with 1 part of gasoline (18.5:1), which is the leanest practical ratio. Richer or leaner air–fuel ratios cause the engine to misfire badly or not run at all.

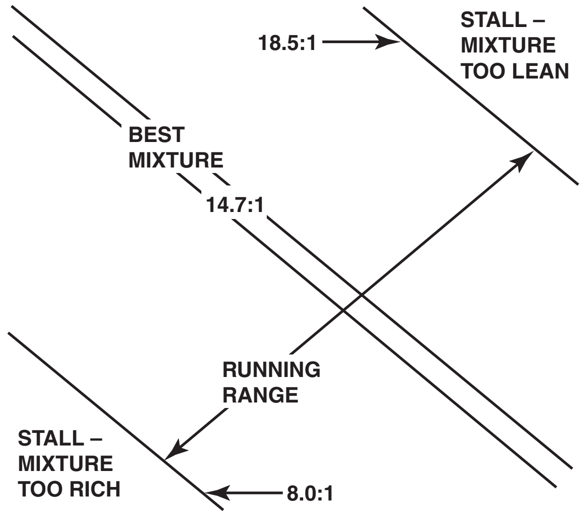

FIGURE 11-10 An engine will not run if the air–fuel mixture is either too rich or too lean.

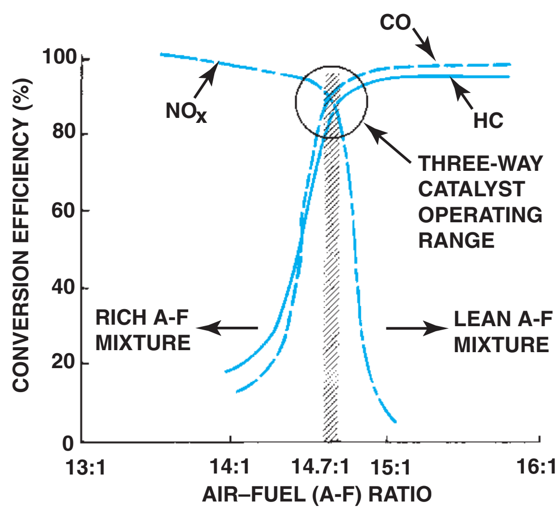

FIGURE 11-11 With a three-way catalytic converter, emission control is most efficient with an air–fuel ratio between 14.65:1 and 14.75:1.

Stoichiometric Air–Fuel Ratio

The ideal mixture or ratio at which all of the fuel combines with all of the oxygen in the air and burns completely is called the **stoichiometric** ratio, a chemically perfect combination. In theory, this ratio is an air–fuel mixture of 14.7 to 1. See Figure 11-11.

In reality, the exact ratio at which perfect mixture and combustion occurs depends on the molecular structure of gasoline, which can vary. The stoichiometric ratio is a compromise between maximum power and maximum economy.

Stoichiometric Air–Fuel Ratio for Various Fuels

If the combustion process is complete, all gasoline or HCs will be completely combined with all the available oxygen. This total combination of all components of the fuel is called *stoichiometric air–fuel ratio.* The stoichiometric quantities for gasoline are 14.7 parts air for 1 part gasoline by weight. Different fuels have different stoichiometric proportions. See the accompanying table comparing the heat and stoichiometric ratio for alcohol versus gasoline.

Fuel	*Heat Energy (BTU/gal)*	*Stoichiometric Ratio*
Gasoline	About 130,000	14.7:1
Ethyl (ethanol) alcohol	About 76,000	9.0:1
Methyl (methanol) alcohol	About 60,000	6.4:1

The heat produced by the combustion process is measured in British thermal units (BTUs). One BTU is the amount of heat required to raise one pound of water one Fahrenheit degree. The metric unit of heat is the calorie (cal). One calorie is the amount of heat required to raise the temperature of one gram (g) of water one Celsius degree.

HIGH-ALTITUDE OCTANE REQUIREMENTS

As the altitude increases, atmospheric pressure drops. The air is less dense because a pound of air takes more volume. The octane rating of fuel does not need to be as high because the engine cannot take in as much air. This process will reduce the combustion (compression) pressures inside the engine. In mountainous areas, gasoline (R + M) = 2 octane ratings are two or more numbers lower than normal (according to the SAE, about one octane number lower per 1,000 ft or 300 m in altitude). See Figure 11-12.

A secondary reason for the lowered octane requirement of engines running at higher altitudes is the normal enrichment of the air–fuel ratio and lower engine vacuum with the decreased air density. Some problems, therefore, may occur when driving out of high-altitude areas into lower-altitude areas where the octane rating must be higher. Most computerized engine control systems can compensate for changes in altitude and modify air–fuel ratio and ignition timing for best operation.

Because the combustion burn rate slows at high altitude, the ignition (spark) timing can be advanced to improve power. The amount of timing advance can be about 1 degree per 1,000 ft over 5,000 ft. Therefore, if driving at 8,000 ft of altitude, the ignition timing can be advanced 3 degrees.

FIGURE 11-12 Photo of gasoline pump taken in a high-altitude area. Note the lower-than-normal octane ratings. The "ethanol" sticker reads that all grades contain 10% ethanol from November 1 through February 28 each year to help reduce CO exhaust emissions.

High altitude also allows fuel to evaporate more easily. The volatility of fuel should be reduced at higher altitudes to prevent vapor from forming in sections of the fuel system, which can cause driveability and stalling problems. The extra heat generated in climbing to higher altitudes plus the lower atmospheric pressure at higher altitudes combine to cause vapor lock problems as the vehicle goes to higher altitudes.

REFORMULATED GASOLINE

Reformulated gasoline (RFG) is manufactured by refiners to help reduce emissions. The gasoline refiners reformulate gasoline by using additives that contain at least 2% oxygen by weight and reducing the additive benzene to a maximum of 1% by volume. Two other major changes done at the refineries are as follows:

1. **Reduce light compounds.** Refineries eliminate butane, pentane, and propane, which have a low boiling point and evaporate easily. These unburned hydrocarbons are released into the atmosphere during refueling and through the fuel tank vent system, contributing to smog formation. Therefore, reducing the light compounds from gasoline helps reduce evaporative emissions.
2. **Reduce heavy compounds.** Refineries eliminate heavy compounds with high boiling points such as aromatics and olefins. The purpose of this reduction is to reduce the amount of unburned hydrocarbons that enter the catalytic converter, which makes the converter more efficient, thereby reducing emissions.

Because many of the heavy compounds are eliminated, a drop in fuel economy of about 1 mpg has been reported in areas where reformulated gasoline is being used. Formaldehyde

FREQUENTLY ASKED QUESTION

WHAT IS "TOP-TIER" GASOLINE?

Top-tier gasoline is gasoline that has specific standards for quality, including enough detergent to keep all intake valves clean. The standards were developed by the four automobile manufacturers, including BMW, General Motors, Honda, and Toyota. Top-tier gasoline exceeds the quality standards developed by the **World Wide Fuel Charter (WWFC)** that was established in 2002 by vehicle and engine manufacturers. The gasoline companies that agreed to make fuel that matches or exceeds the standards as a top-tier fuel include Chevron Texaco and Conoco Phillips. Ford has specified that BP fuel, sold in many parts of the country, is the recommended fuel to use in Ford vehicles. See Figure 11-13.

FIGURE 11-13 The gas cap on a Ford vehicle notes that BP fuel is recommended.

is formed when RFG is burned, and the vehicle exhaust has a unique smell when reformulated gasoline is used.

GENERAL GASOLINE RECOMMENDATIONS

The fuel used by an engine is a major expense in the operation cost of the vehicle. The proper operation of the engine depends on clean fuel of the proper octane rating and vapor pressure for the atmospheric conditions.

FREQUENTLY ASKED QUESTION

WHY SHOULD I KEEP THE FUEL GAUGE ABOVE ONE-QUARTER TANK?

The fuel pickup inside the fuel tank can help keep water from being drawn into the fuel system unless water is all that is left at the bottom of the tank. Over time, moisture in the air inside the fuel tank can condense, causing liquid water to drop to the bottom of the fuel tank (water is heavier than gasoline—about 8 lb per gallon for water and about 6 lb per gallon for gasoline). If alcohol-blended gasoline is used, the alcohol can absorb the water and the alcohol–water combination can be burned inside the engine. However, when water combines with alcohol, a separation layer occurs between the gasoline at the top of the tank and the alcohol–water combination at the bottom. When the fuel level is low, the fuel pump will draw from this concentrated level of alcohol and water. Because alcohol and water do not burn as well as pure gasoline, severe driveability problems can occur such as stalling, rough idle, hard starting, and missing.

To help ensure proper engine operation and keep fuel costs to a minimum, follow these guidelines:

1. Purchase fuel from a busy station to help ensure that it is fresh and less likely to be contaminated with water or moisture.
2. Keep the fuel tank above one-quarter full, especially during seasons in which the temperature rises and falls by more than 20°F between daytime highs and nighttime lows. This helps to reduce condensed moisture in the fuel tank and could prevent gas line freeze-up in cold weather.

   NOTE: Gas line freeze-up occurs when the water in the gasoline freezes and forms an ice blockage in the fuel line.

3. Do not purchase fuel with a higher octane rating than is necessary. Try using premium high-octane fuel to check for operating differences. Most newer engines are equipped with a detonation (knock) sensor that signals the vehicle computer to retard the ignition timing when spark knock occurs. Therefore, an operating difference may not be noticeable to the driver when using a low-octane fuel, except

TECH TIP

DO NOT OVERFILL THE FUEL TANK

Gasoline fuel tanks have an expansion volume area at the top. The volume of this expansion area is equal to 10% to 15% of the volume of the tank. This area is normally not filled with gasoline, but rather is designed to provide a place for the gasoline to expand into, if the vehicle is parked in the hot sun and the gasoline expands. This prevents raw gasoline from escaping from the fuel system. A small restriction is usually present to control the amount of air and vapors that can escape the tank and flow to the charcoal canister.

This volume area could be filled with gasoline if the fuel is slowly pumped into the tank. Since it can hold an extra 10% (2 gallons in a 20-gallon tank), some people deliberately try to fill the tank completely. When this expansion volume is filled, liquid fuel (rather than vapors) can be drawn into the charcoal canister. When the purge valve opens, liquid fuel can be drawn into the engine, causing an excessively rich air–fuel mixture. Not only can this liquid fuel harm vapor recovery parts, but overfilling the gas tank could also cause the vehicle to fail an exhaust emission test, particularly during an enhanced test when the tank could be purged while on the rollers.

for a decrease in power and fuel economy. In other words, the engine with a knock sensor will tend to operate knock free on regular fuel, even if premium, higher-octane fuel is specified. Using premium fuel may result in more power and greater fuel economy. The increase in fuel economy, however, would have to be substantial to justify the increased cost of high-octane premium fuel. Some drivers find a good compromise by using midgrade (plus) fuel to benefit from the engine power and fuel economy gains without the cost of using premium fuel all the time.

4. Avoid using gasoline with alcohol in warm weather, even though many alcohol blends do not affect engine driveability. If warm-engine stumble, stalling, or rough idle occurs, change brands of gasoline.
5. Do not purchase fuel from a retail outlet when a tanker truck is filling the underground tanks. During the refilling procedure, dirt, rust, and water may be stirred up in the underground tanks. This undesirable material may be pumped into your vehicle's fuel tank.

FIGURE 11-14 Many gasoline service stations have signs posted warning customers to place plastic fuel containers on the ground while filling. If placed in a trunk or pickup truck bed equipped with a plastic liner, static electricity could build up during fueling and discharge from the container to the metal nozzle, creating a spark and possible explosion. Some service stations have warning signs not to use cell phones while fueling to help avoid the possibility of an accidental spark creating a fire hazard.

6. Do not overfill the gas tank. After the nozzle clicks off, add just enough fuel to round up to the next dime. Adding additional gasoline will cause the excess to be drawn into the charcoal canister. This can lead to engine flooding and excessive exhaust emissions.
7. Be careful when filling gasoline containers. Always fill a gas can on the ground to help prevent the possibility of static electricity build-up during the refueling process. See Figure 11-14.

ALTERNATIVE FUELS

Alternative fuels include a number of fuels besides gasoline for use in passenger vehicles. See Figure 11-15.

FIGURE 11-15 Some retail stations offer a variety of fuel choices, such as this station in Ohio where biodiesel, E10, and E85 are available.

Ethanol

Ethanol is also called ethyl alcohol or **grain alcohol,** because it is usually made from grain and is the type of alcohol found in alcoholic drinks such as beer, wine, and distilled spirits like whiskey. Ethanol is composed of two carbon atoms and six hydrogen atoms with one added oxygen atom. See Figure 11-16.

Conventional ethanol and **cellulose ethanol** are the same product, but cellulose ethanol is produced using the nonfood portion of the feedstock. Conventional ethanol is derived from grains, such as corn, wheat, or soybeans. Corn, for example, is converted to ethanol in either a dry or wet milling process. In dry milling operations, liquefied cornstarch is produced by heating cornmeal with water and enzymes. A second enzyme converts the liquefied starch to sugars, which are fermented by yeast into ethanol and carbon dioxide. Wet milling operations separate the fiber, germ (oil), and protein from the starch before it is fermented into ethanol.

Cellulose ethanol can be produced from a wide variety of cellulose biomass feedstock, including agricultural plant wastes (corn stalks, cereal straws), plant wastes from industrial processes (sawdust, paper pulp), and energy crops grown specifically for fuel production. These nongrain products are often referred to as **cellulosic biomass.** Cellulosic biomass is composed of cellulose and lignin, with smaller amounts of proteins, lipids (fats, waxes, and oils), and ash. About two-thirds of cellulosic materials are present as cellulose, with lignin making up the bulk of the remaining dry mass.

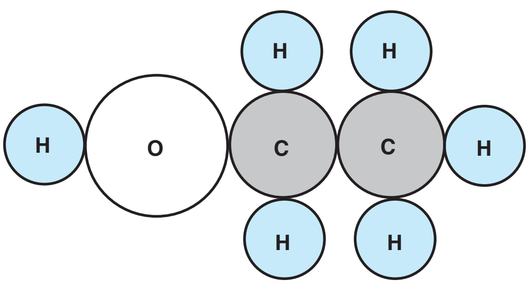

FIGURE 11-16 The ethanol molecule showing two carbon atoms, six hydrogen atoms, and one oxygen atom.

As with grains, processing cellulose biomass strives to extract fermentable sugars from the feedstock. But the sugars in cellulose are locked in complex carbohydrates called polysaccharides (long chains of simple sugars). Separating these complex structures into fermentable sugars is needed to achieve the efficient and economic production of cellulose ethanol.

Two processing options are employed to produce fermentable sugars from cellulose biomass:

- Acid hydrolysis is used to break down the complex carbohydrates into simple sugars.
- Enzymes are employed to convert the cellulose biomass to fermentable sugars. The final step involves microbial fermentation, yielding ethanol and carbon dioxide.

NOTE: Grain-based ethanol uses fossil fuels to produce heat during the conversion process, generating substantial greenhouse gas emissions. Cellulose ethanol production substitutes biomass for fossil fuels. The greenhouse gases produced by the combustion of biomass are offset by the CO_2 absorbed by the biomass as it grows in the field.

The majority of the ethanol in the United States is made from:

- Corn
- Grain
- Sorghum
- Wheat
- Barley
- Potatoes

In Brazil, the world's largest ethanol producer, it is made from sugarcane. Ethanol can be made by the dry mill process in which the starch portion of the corn is fermented into sugar and then distilled into alcohol.

The major steps in the dry mill process include:

1. **Milling.** The feedstock passes through a hammer mill that turns it into a fine powder called meal.
2. **Liquefaction.** The meal is mixed with water and then passed through cookers where the starch is liquefied. Heat is applied at this stage to enable liquefaction. Cookers use a high-temperature stage of about 250°F to 300°F (120°C to 150°C) to reduce bacteria levels and then a lower temperature of about 200°F (95°C) for a holding period.

FREQUENTLY ASKED QUESTION

DOES ETHANOL PRODUCTION HARM THE ENVIRONMENT?

The production of ethanol is referred to as being *carbon neutral* because the amount of CO_2 released during production is equal to the amount of CO_2 that would be released if the corn or other products were left to decay.

3. **Saccharification.** The mash from the cookers is cooled and the secondary enzyme is added to convert the liquefied starch to fermentable sugars (dextrose).
4. **Fermentation.** Yeast is added to the mash to ferment the sugars to ethanol and carbon dioxide.
5. **Distillation.** The fermented mash, now called beer, contains about 10% alcohol plus all the nonfermentable solids from the corn and yeast cells. The mash is pumped to the continuous-flow, multicolumn distillation system where the alcohol is removed from the solids and the water. The alcohol leaves the top of the final column at about 96% strength, and the residue mash, called silage, is transferred from the base of the column to the co-product processing area.
6. **Dehydration.** The alcohol from the top of the column passes through a dehydration system where the remaining water will be removed. Most ethanol plants use a molecular sieve to capture the last bit of water in the ethanol. The alcohol product at this stage is called **anhydrous ethanol** (pure, no more than 5% water).
7. **Denaturing.** Ethanol that will be used for fuel must be denatured, or made unfit for human consumption, with a small amount of gasoline (2–5%), methanol, or denatonium benzoate. This is done at the ethanol plant.

E85

Vehicle manufacturers have available vehicles that are capable of operating on gasoline plus ethanol or a combination of gasoline and ethanol called **E85.** E85 is composed of 85% ethanol and 15% gasoline. Pure ethanol has an octane rating of about 113, whereas E85, which contains 35% oxygen by weight, has an octane rating of about 100 to 105 compared to a regular unleaded gasoline rating of 87.

NOTE: **The octane rating of E85 depends on the exact percent of ethanol used, which can vary from 81% to 85%, as well as the octane rating of the gasoline used.**

E85 has less heat energy than gasoline.

Gasoline = 114,000 BTUs per gallon
E85 = 87,000 BTUs per gallon

This means that the fuel economy is reduced by 20% to 30% if E85 is used instead of gasoline.

For example, a Chevrolet Tahoe 5.3-liter V-8, automatic transmission has an EPA rating using gasoline of 15 mpg in the city and 20 mpg on the highway. If this same vehicle was fueled with E85, the EPA fuel economy rating drops to 11 mpg in the city and 15 mpg on the highway.

The 15% gasoline in this blend helps the engine start, especially in cold weather. Vehicles equipped with this capability are commonly referred to as **alternative-fuel vehicles (AFVs), Flex Fuels,** and **flexible fuel vehicles,** or **FFV.** See Figure 11-17. Using E85 in a flex fuel vehicle can result in a power increase of about 5%. For example, an engine rated at 200 hp using gasoline or E10 could produce 210 hp if using E85.

NOTE: **E85 may test as containing less than 85% ethanol if tested because it is often blended according to outside temperature. A lower percentage of ethanol with a slightly higher percentage of gasoline helps engines start in cold climates.**

These vehicles are equipped with an electronic sensor that detects the fuel temperature and percentage of ethanol and then programs the fuel injector on-time and ignition timing to match the needs of the fuel being used.

E85 contains less heat energy, and therefore will use more fuel, but the benefits include a lower cost of the fuel and

FIGURE 11-17 A vehicle emission control information (VECI) sticker on a flexible fuel vehicle indicating the percentage of ethanol with which it is able to operate.

the environmental benefit associated with using an oxygenated fuel.

General Motors, Ford, Chrysler, Mazda, and Honda are a few of the manufacturers offering E85–compatible vehicles. E85 vehicles use fuel system parts designed to withstand the additional alcohol content, modified driveability programs that adjust fuel delivery and timing to compensate for the various percentages of ethanol fuel, and a **fuel compensation sensor,** also called a **fuel composition sensor,** which measures both the percentage of ethanol blend and the temperature of the fuel. This sensor is also called a **variable fuel sensor.** See Figures 11-18 and 11-19.

Most E85 vehicles are very similar to non-E85 vehicles. Fuel system components may be redesigned to withstand the effects of higher concentrations of ethanol. In addition, since the stoichiometric point for ethanol is 9:1 instead of 14.7:1 as for gasoline, the air–fuel mixture has to be adjusted for the percentage of ethanol present in the fuel tank. In order to determine this percentage of ethanol in the fuel tank, a fuel compensation sensor is used. The fuel compensation sensor is the only additional piece of hardware required on some E85 vehicles. The fuel compensation sensor provides both the ethanol percentage and the fuel temperature to the PCM. The PCM uses this information to adjust both the ignition timing and the quantity of fuel delivered to the engine. The fuel compensation sensor uses a microprocessor to measure both the ethanol percentage and the fuel temperature. This information is sent to the PCM on the signal circuit. The compensation sensor produces a square wave frequency and pulse width signal. The normal frequency range of the fuel compensation sensor is 50 hertz, which represents 0% ethanol, and 150 hertz, which represents 100% ethanol. The pulse width of the signal varies from 1 millisecond to 5 milliseconds. One millisecond would represent a fuel temperature of −40°F (−40°C), and 5 milliseconds would represent a fuel temperature of 257°F (125°C). Since the PCM knows both the fuel temperature and the ethanol percentage of the fuel, it can adjust fuel quantity and ignition timing for optimum performance and emissions.

The benefits of E85 vehicles are less pollution, less CO_2 production, and less dependence on oil. See Figure 11-20.

Ethanol-fueled vehicles generally produce the same pollutants as gasoline vehicles; however, they produce less CO and CO_2 emissions. While CO_2 is not considered a pollutant, it is thought to lead to global warming and is called a greenhouse gas.

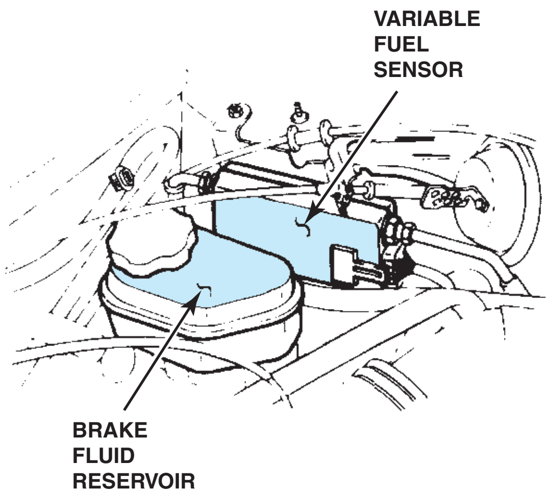

FIGURE 11-18 The location of the variable fuel sensor can vary, depending on the make and model of vehicle, but it is always in the fuel line between the fuel tank and the fuel injectors.

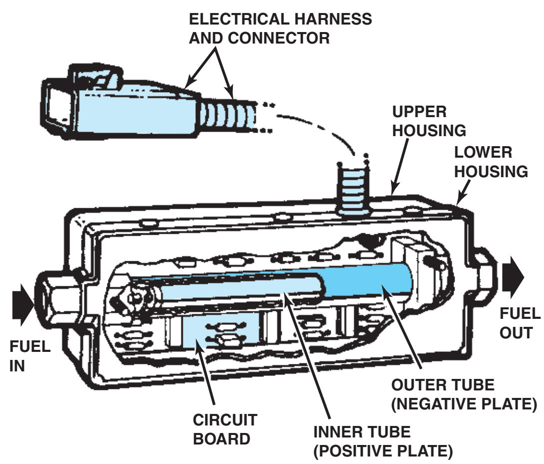

FIGURE 11-19 A cutaway view of a typical variable fuel sensor.

FREQUENTLY ASKED QUESTION

HOW DOES A SENSORLESS FLEX FUEL SYSTEM WORK?

Many General Motors flex fuel vehicles do not use a fuel compensation sensor and instead use the oxygen sensor to detect the presence of the lean mixture and the extra oxygen in the fuel.

The powertrain control module (PCM) then adjusts the injector pulse width and the ignition timing to optimize engine operation to the use of E85. This type of vehicle is called a virtual flexible fuel vehicle, abbreviated **V-FFV.** The virtual flexible fuel vehicle can operate on pure gasoline, E10, E85, or any combination.

FIGURE 11-20 A pump for E85 (85% ethanol and 15% gasoline). There are few, if any, of these pumps in many states.

FREQUENTLY ASKED QUESTION

WHAT IS SWITCHGRASS?

Switchgrass (*Panicum virgatum*) is a summer perennial grass that is native to North America. It is a natural component of the tall-grass prairie, which covered most of the Great Plains, but was also found on the prairie soils in the Black Belt of Alabama and Mississippi. Switchgrass is resistant to many pests and plant diseases, and is capable of producing high yields with very low applications of fertilizer. This means that the need for agricultural chemicals to grow switchgrass is relatively low. Switchgrass is also very tolerant of poor soils, flooding, and drought, which are widespread agricultural problems in the southeast.

There are two main types of switchgrass:

- *Upland types*—usually grow 5 to 6 feet tall
- *Low-land types*—grow up to 12 feet tall and are typically found on heavy soils in bottomland sites

Better energy efficiency is gained because less energy is used to produce ethanol from switchgrass.

TECH TIP

AVOID RESETTING FUEL COMPENSATION

Starting in 2006, General Motors vehicles designed to operate on E85 do not use a fuel compensation sensor, but instead use the oxygen sensor and refueling information to calculate the percentage of ethanol in the fuel. The PCM uses the fuel level sensor to sense that fuel has been added and starts to determine the resulting ethanol content by using the oxygen sensor. However, if a service technician were to reset fuel compensation by clearing long-term fuel trim, the PCM starts the calculation based on base fuel, which is gasoline with less than or equal to 10% ethanol (E10). If the fuel tank has E85, then the fuel compensation cannot be determined unless the tank is drained and refilled with base fuel. Therefore, avoid resetting the fuel compensation setting unless it is known that the fuel tank contains gasoline or E10 only.

Flex Fuel Vehicles

Vehicles that are flexible fuel include:

Chrysler

2004–2005

- 4.7L Dodge Ram Pickup 1500 Series
- 2.7L Dodge Stratus Sedan
- 2.7L Chrysler Sebring Sedan
- 3.3L Caravan and Grand Caravan SE

2003–2004

- 2.7L Dodge Stratus Sedan
- 2.7L Chrysler Sebring Sedan

2003

- 3.3L Dodge Cargo Minivan

2000–2003

- 3.3L Chrysler Voyager Minivan
- 3.3L Dodge Caravan Minivan
- 3.3L Chrysler Town and Country Minivan

1998–1999

- 3.3L Dodge Caravan Minivan
- 3.3L Plymouth Voyager Minivan
- 3.3L Chrysler Town & Country Minivan

Ford Motor Company

*Ford offers the flex fuel capability as an option on select vehicles—see the owner's manual.

2004–2005

- 4.0L Explorer Sport Trac
- 4.0L Explorer (4-door)
- 3.0L Taurus Sedan and Wagon

2002–2004

- 4.0L Explorer (4-door)
- 3.0L Taurus Sedan and Wagon

2002–2003

- 3.0L Supercab Ranger Pickup 2WD

2001

- 3.0L Supercab Ranger Pickup 2WD
- 3.0L Taurus LX, SE, and SES Sedan

1999–2000

- 3.0L Ranger Pickup 4WD and 2WD

General Motors

*Select vehicles only—see your owner's manual.

2005

- 5.3L Vortec-Engine Avalanche
- 5.3L Vortec-Engine Police Package Tahoe

2003–2005

- 5.3L V8 Chevy Silverado* and GMC Sierra* Half-Ton Pickups, 2WD and 4WD
- 5.3L Vortec-Engine Suburban, Tahoe, Yukon, and Yukon XL

2002

- 5.3L V8 Chevy Silverado* and GMC Sierra* Half-Ton Pickups, 2WD and 4WD
- 5.3L Vortec-Engine Suburban, Tahoe, Yukon, and Yukon XL
- 2.2L Chevy S10 Pickup 2WD
- 2.2L Sonoma GMC Pickup 2WD

2000–2001

- 2.2L Chevy S10 Pickup 2WD
- 2.2L GMC Sonoma Pickup 2WD

Isuzu

2000–2001

- 2.2L Hombre Pickup 2WD

Mazda

1999–2003

- 3.0L Selected B3000 Pickups

Mercedes-Benz

2005

- 2.6L C240 Luxury Sedan and Wagon

2003

- 3.2L C320 Sport Sedan and Wagon

Mercury

2002–2004

- 4.0L Selected Mountaineers

2000–2004

- 3.0L Selected Sables

Nissan

*Select vehicles only—see the owner's manual or VECI sticker under the hood.

2005

- 5.6L DOHC V8 Engine

How to Read a Vehicle Identification Number

The vehicle identification number (VIN) is required by federal regulation to contain specific information about the vehicle. The following chart shows the VIN number and information from Ford Motor Company, General Motors, and Chrysler on identifying flexible fuel vehicles by the character in the eighth position in the VIN.

Ford Motor Company

Vehicle	8th Character
Ford Crown Victoria	V
Ford F-150	V
Ford Explorer	K
Ford Ranger	V
Ford Taurus	2
Lincoln Town Car	V
Mercury Mountaineer	K
Mercury Sable	2
Mercury Grand Marquis	V

General Motors

Vehicle	8th Character
Chevrolet Avalanche	Z
Chevrolet Impala	K
Chevrolet Monte Carlo	K

Vehicle	8th Character
Chevrolet S-10 Pickup	5
Chevrolet Sierra	Z
Chevrolet Suburban	Z
Chevrolet Tahoe	Z
GMC Yukon and Yukon XL	Z
GMC Silverado	Z
GMC Sonoma	5

Chrysler

Vehicle	8th Character
Chrysler Sebring	T
Chrysler Town and Country	E, G, or 3
Dodge Caravan	E, G, or 3
Dodge Cargo Minivan	E, G, or 3
Dodge Durango	P
Dodge Ram	P
Dodge Stratus	T
Plymouth Voyager	E, G, or 3

Mazda

Vehicle	8th Character
B3000 Pickup	V

Nissan

Vehicle	8th Character
Titan	B

Mercedes Benz

Check owner's manual or the VECI sticker under the hood.

NOTE: For additional information on E85 and for the location of E85 stations in your area go to *www.e85fuel.com*.

Methanol

Methanol, also known as *methyl alcohol* or *wood alcohol*, is a chemical compound with a chemical formula that includes one carbon atom and four hydrogen atoms and one oxygen. See Figure 11-21.

Methanol is a light, volatile, colorless, tasteless, flammable, poisonous liquid with a very faint odor. It is used as an antifreeze, solvent, and fuel, and to denature ethanol. Methanol burns in air, forming CO_2 (carbon dioxide) and H_2O (water). A methanol flame is almost colorless. Because of its poisonous properties, methanol is also used to denature ethanol. Methanol is often called wood alcohol because it was once produced chiefly as a by-product of the destructive distillation of wood. See Figure 11-22.

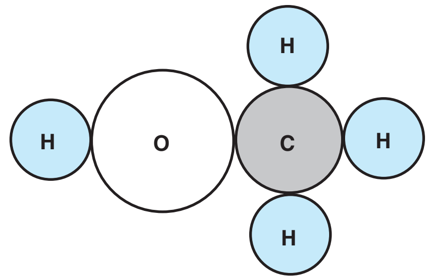

FIGURE 11-21 The molecular structure of methanol showing the one carbon atom, four hydrogen atoms, and one oxygen atom.

FIGURE 11-22 Sign on methanol pump shows that methyl alcohol is a poison and can cause skin irritation and other personal injury. Methanol is used in industry as well as a fuel source.

The biggest source of methanol in the United States is coal. Using a simple reaction between coal and steam, a gas mixture called **syn-gas (synthesis gas)** is formed. The components of this mixture are carbon monoxide and hydrogen, which, through an additional chemical reaction, are converted to methanol.

Natural gas can also be used to create methanol and is reformed or converted to synthesis gas, which is later made into methanol.

Biomass can be converted to synthesis gas by a process called partial oxidation, and later converted to methanol. **Biomass** is organic material, such as urban wood wastes, primary mill residues, forest residues, agricultural residues, and dedicated energy crops (e.g., sugarcane and sugar beets), that can be made into fuel.

Electricity can be used to convert water into hydrogen, which is then reacted with carbon dioxide to produce methanol.

Methanol is toxic and can cause blindness and death. It can enter the body by ingestion, inhalation, or absorption through the skin. Dangerous doses will build up if a person is regularly exposed to fumes or handles liquid without skin protection. If methanol has been ingested, a doctor should be contacted immediately. The usual fatal dose is 4 fl oz (100–125 mL).

M-85

Some flexible fuel vehicles are designed to operate on 85% methanol and 15% gasoline. Methanol is very corrosive and requires that the fuel system components be constructed of stainless steel and other alcohol-resistant rubber and plastic components. The heat content of **M85** is about 60% of that of gasoline.

Propane

Propane is normally a gas but is easily compressed into a liquid and stored in inexpensive containers. When sold as a fuel, it is also known as **liquefied petroleum gas (LPG)** or LP-gas because the propane is often mixed with about 10% of other gases such as butane, propylene, butylenes, and mercaptan to give the colorless and odorless propane a smell. Propane is nontoxic, but if inhaled can cause asphyxiation through lack of oxygen. Propane is heavier than air and lays near the floor if released into the atmosphere. Propane is commonly used in forklifts and other equipment used inside warehouses and factories because the exhaust from the engine using propane is not harmful. Propane comes from a by-product of petroleum refining of natural gas. In order to liquefy the fuel, it is stored in strong tanks at about 300 PSI (2,000 kPa). The heating value of propane is less than that of gasoline; therefore, more is required, which reduces the fuel economy. See Figure 11-23.

FIGURE 11-23 Propane fuel storage tank in the trunk of a Ford taxi.

Compressed Natural Gas (CNG)

Another alternative fuel that is often used in fleet vehicles is **compressed natural gas**, or **CNG,** and vehicles using this fuel are often referred to as **natural gas vehicles (NGVs)**. Look for the blue CNG label on vehicles designed to operate on compressed natural gas. See Figure 11-24.

Natural gas has to be compressed to about 3,000 PSI (20,000 kPa) or more, so that the weight and the cost of the storage container is a major factor when it comes to preparing a vehicle to run on CNG. The tanks needed for CNG are typically constructed of 0.5-inch-thick (3 mm) aluminum reinforced with fiberglass. The octane rating of CNG is about 130 and the cost per gallon is about half of the cost of gasoline. However, the heat value of CNG is also less, and therefore more is required to produce the same power and the miles per gallon is less.

Compressed natural gas is made up of a blend of methane, propane, ethane, N-butane, carbon dioxide, and nitrogen. Once it is processed, it is at least 93% methane. Natural gas is nontoxic, odorless, and colorless in its natural state. It is odorized during processing, using ethyl mercaptan ("skunk"), to allow for easy leak detection. Natural gas is lighter than air and will rise when released into the air. Since CNG is already a vapor, it does not need heat to vaporize before it will burn, which improves cold start-up and results in lower emissions during cold operation. However, because it is already in a gaseous state, it does displace some of the air charge in the intake manifold. This leads to about a 10% reduction in engine power as compared to an engine operating on gasoline. Natural gas also burns slower than gasoline; therefore, the ignition timing must be advanced more when the vehicle operates on natural gas. Natural gas has an octane rating of about 115 octane. The stoichiometric ratio, the point at which all the air and fuel is used or burned, is 16.5:1 compared to 14.7:1 for gasoline. This means that more air is required to burn one pound of natural gas than is required to burn one pound of gasoline. See Figure 11-25.

FIGURE 11-24 The blue sticker on the rear of this vehicle indicates that it is designed to use compressed natural gas.

FIGURE 11-25 The fuel injectors used on this Honda Civic GX CNG engine are designed to flow gaseous fuel instead of liquid fuel and cannot be interchanged with any other type of injector.

FIGURE 11-26 A CNG storage tank from a Honda Civic GX shown with the fixture used to support it while it is being removed or installed in the vehicle. Honda specifies that three technicians be used to remove or install the tank through the rear door of the vehicle due to the size and weight of the tank.

The CNG engine is designed to include:

- Increased compression ratio
- Strong pistons and connecting rods
- Heat-resistant valves
- Fuel injectors designed for gaseous fuel instead of liquid fuel

When completely filled, the CNG tank has 3,600 PSI of pressure in the tank. When the ignition is turned on, the alternate fuel electronic control unit activates the high-pressure lock-off, which allows high-pressure gas to pass to the high-pressure regulator. The high-pressure regulator reduces the high-pressure CNG to approximately 170 PSI and sends it to the low-pressure lock-off. The low-pressure lock-off is also controlled by the alternate fuel electronic control unit and is activated at the same time that the high-pressure lock-off is activated. From the low-pressure lock-off, the CNG is directed to the low-pressure regulator. This is a two-stage regulator that first reduces the pressure to approximately 4 to 6 PSI in the first stage and then to 4.5 to 7 inches of water in the second stage. From here, the low-pressure gas is delivered to the gas mass sensor/mixture control valve. This valve controls the air–fuel mixture. The CNG gas distributor adapter then delivers the gas to the intake stream.

CNG vehicles are designed for fleet use that usually have their own refueling capabilities. One of the drawbacks to using CNG is the time that it takes to refuel a vehicle. The ideal method of refueling is the slow fill method. The slow filling method compresses the natural gas as the tank is being fueled. This method ensures that the tank will receive a full charge of CNG; however, this method can take three to five hours to accomplish. If more than one vehicle needs filling, the facility will need multiple CNG compressors to refuel the vehicles. There are three commonly used CNG refilling station pressures:

P24—2,400 PSI
P30—3,000 PSI
P36—3,600 PSI

Try to find and use a station with the highest pressure to help ensure a long driving range. Filling at lower pressures will result in less compressed natural gas being installed in the storage tank, thereby reducing the driving range. See Figure 11-26.

The fast fill method uses CNG that is already compressed. However, as the CNG tank is filled rapidly, the internal temperature of the tank will rise, which causes a rise in tank pressure. Once the temperature drops in the CNG tank, the pressure in the tank also drops, resulting in an incomplete charge in the CNG tank. This refueling method may take only about five minutes; however, it will result in an incomplete charge to the CNG tank, reducing the driving range.

P-SERIES FUELS

P-series alternative fuel is patented by Princeton University and is a non-petroleum-based fuel suitable for use in flexible fuel vehicles or any vehicle designed to operate on E85 (85% ethanol, 15% gasoline). P-series fuels are blends of the following:

- Ethanol (ethyl alcohol)
- Methyltetrahydrofuron, abbreviated **MTHF**
- Natural gas liquids, such as pentanes
- Butane

The ethanol and MTHF are produced from renewable feedstocks, such as corn, waste paper, biomass, agricultural waste, and wood waste (scraps and sawdust). The components used in P-type fuel can be varied to produce regular grade, premium grade, or fuel suitable for cold climates.

Composition of P-Series Fuels (by volume)

Component	Regular Grade	Premium Grade	Cold Weather
Pentanes plus	32.5%	27.5%	16.0%
MTHF	32.5%	17.5%	26.0%
Ethanol	35.0%	55.0%	47.0%
Butane	0.0%	0.0%	11.0%

See the following comparison chart that summarizes the characteristics of the most commonly used fuels.

The advantages of P-series alternative fuels include:

- Can be used as produced without being mixed with gasoline.
- The cost is slightly less to produce than gasoline, and heat produced when used in an engine is also slightly less, making it a suitable alternative to gasoline.

FREQUENTLY ASKED QUESTION

WHAT IS A TRI-FUEL VEHICLE?

In Brazil, most vehicles are designed to operate on ethanol or gasoline or any combination of the two. In this South American country, ethanol is made from sugarcane, is commonly available, and is lower in price than gasoline. Compressed natural gas (CNG) is also being made available, so many vehicle manufacturers in Brazil, such as General Motors and Ford, are equipping vehicles to be capable of using gasoline, ethanol, or CNG. These vehicles are called tri-fuel vehicles.

The disadvantages include:

- Limited availability
- Can only be used in flexible fuel vehicles (FFV)

Alternate Fuel Comparison Chart

Characteristic	Propane	CNG	Methanol	Ethanol	Regular Unleaded Gas
Octane	104	130	100	100	87–93
BTU per gallon	91,000	N.A.	70,000	83,000	114,000–125,000
Gallon equivalent	1.15	122 cubic feet–1 gallon of gasoline	1.8	1.5	1
On-board fuel storage	Liquid	Gas	Liquid	Liquid	Liquid
Miles/gallon as compared to gas	85%	N.A.	55%	70%	100%
Relative tank size required to yield driving range equivalent to gas	Tank is 1.25 times larger	Tank is 3.5 times larger	Tank is 1.8 times larger	Tank is 1.5 times larger	
Pressure	200 PSI	3,000–3,600 PSI	N.A.	N.A.	N.A.
Cold weather capability	Good	Good	Poor	Poor	Good
Vehicle power	5–10% power loss	10–20% power loss	4% power increase	5% power increase	Standard
Toxicity	Nontoxic	Nontoxic	Highly toxic	Toxic	Toxic
Corrosiveness	Noncorrosive	Noncorrosive	Corrosive	Corrosive	Minimally corrosive
Source	Natural gas/ petroleum refining	Natural gas/ crude oil	Natural gas/coal	Sugar and starch crops/biomass	Crude oil

DIESEL FUEL

Diesel fuel must meet an entirely different set of standards than gasoline. The fuel in a diesel engine is not ignited with a spark, but is ignited by the heat generated by high compression. The pressure of compression (400 to 700 PSI, or 2,800 to 4,800 kilopascals) generates temperatures of 1,200° to 1,600°F (700° to 900°C), which speeds the preflame reaction to start the ignition of fuel injected into the cylinder.

All diesel fuel must be clean, be able to flow at low temperatures, and be of the proper cetane rating.

- **Cleanliness.** It is imperative that the fuel used in a diesel engine be clean and free from water. Unlike the case with gasoline engines, the fuel is the lubricant and coolant for the diesel injector pump and injectors. Good-quality diesel fuel contains additives such as oxidation inhibitors, detergents, dispersants, rust preventatives, and metal deactivators.
- **Low-temperature fluidity.** Diesel fuel must be able to flow freely at all expected ambient temperatures. One specification for diesel fuel is its "pour point," which is the temperature below which the fuel would stop flowing. Cloud point is another concern with diesel fuel at lower temperatures. Cloud point is the low-temperature point at which the waxes present in most diesel fuels tend to form crystals that clog the fuel filter. Most diesel fuel suppliers distribute fuel with the proper pour point and cloud point for the climate conditions of the area.
- **Cetane number.** The cetane number for diesel fuel is the opposite of the octane number for gasoline. The cetane number is a measure of the ease with which the fuel can be ignited. The **cetane rating** of the fuel determines, to a great extent, its ability to start the engine at low temperatures and to provide smooth warm-up and even combustion. The cetane rating of diesel fuel should be between 45 and 50. The higher the cetane rating, the more easily the fuel is ignited.

Other diesel fuel specifications include its flash point, sulfur content, and classification. The flash point is the temperature at which the vapors on the surface of the fuel will ignite if exposed to an open flame. The flash point does *not* affect diesel engine operation. However, a lower-than-normal flash point could indicate contamination of the diesel fuel with gasoline or a similar substance.

The sulfur content of diesel fuel is very important to the life of the engine. Most engine manufacturers specify that only fuel containing less than about 0.3% sulfur be used. The current limit as set by the American Society for Testing and Materials (ASTM) is 0.5% maximum. Sulfur in the fuel creates sulfuric acid during the combustion process, which can damage engine components and cause piston ring wear. Federal regulations are getting extremely tight on sulfur content. High-sulfur fuel contributes to acid rain.

ASTM also classifies diesel fuel by volatility (boiling range) into the following grades:

Grade #1. This grade of diesel fuel has the lowest boiling point and the lowest cloud and pour points, as well as a lower BTU content—less heat per pound of fuel. As a result, grade #1 is suitable for use during low-temperature (winter) operation. Grade #1 produces less heat per pound of fuel compared to grade #2 and may be specified for use in diesel engines involved in frequent changes in load and speed, such as those found in city buses and delivery trucks.

Grade #2. This grade has a higher boiling point, cloud point, and pour point as compared with grade #1. It is usually specified where constant speed and high loads are encountered, such as in long-haul trucking and automotive diesel applications.

Diesel Fuel Specific Gravity Testing

The density of diesel fuel should be tested whenever there is a driveability concern. The density or specific gravity of diesel fuel is measured in units of **API gravity.** (See the following API Gravity Comparison Chart.) API gravity is an arbitrary scale expressing the gravity or density of liquid petroleum products devised jointly by the American Petroleum Institute and the National Bureau of Standards. The measuring scale is calibrated in terms of degrees API. Oil with the least specific gravity has the highest API gravity. The formula for determining API gravity is as follows:

$$\text{Degree API gravity} = (141.5 \div \text{specific gravity at } 60°\text{F}) - 131.5$$

The normal API gravity for #1 diesel fuel is 39 to 44 (typically 40). The normal API gravity for #2 diesel fuel is 30 to 39 (typically 35). A hydrometer calibrated in API gravity units should be used to test diesel fuel. See Figure 11-27.

Diesel Fuel Heaters

Diesel fuel heaters, either coolant or electric, help prevent power loss and stalling in cold weather. The heater is placed in the fuel line between the tank and the primary filter. Some coolant heaters are thermostatically controlled, which allows fuel to bypass the heater once it has reached operating temperature.

Ultra-Low-Sulfur Diesel Fuel

Diesel fuel is used in diesel engines and is usually readily available throughout the United States, Canada, and Europe, where

FIGURE 11-27
Testing the API viscosity of a diesel fuel sample using a hydrometer.

API Gravity Comparison Chart

API Gravity Scale	Values for API Scale Oil Specific Gravity	Weight Density, lb/ft	Pounds per Gallon
0			
2			
4			
6			
8			
10	1.0000	62.36	8.337
12	0.9861	61.50	8.221
14	0.9725	60.65	8.108
16	0.9593	59.83	7.998
18	0.9465	59.03	7.891
20	0.9340	58.25	7.787
22	0.9218	57.87	7.736
24	0.9100	56.75	7.587
26	0.8984	56.03	7.490
28	0.8871	55.32	7.396
30	0.8762	54.64	7.305
32	0.8654	53.97	7.215
34	0.8550	53.32	7.128
36	0.8448	52.69	7.043
38	0.8348	51.06	6.960
40	0.8251	50.96	6.879
42	0.8155	50.86	6.799
44	0.8030	50.28	6.722
46	0.7972	49.72	6.646
48	0.7883	49.16	6.572
50	0.7796	48.62	6.499
52	0.7711	48.09	6.429
54	0.7628	47.57	6.359
56	0.7547	47.07	6.292
58	0.7467	46.57	6.225
60	0.7389	46.08	6.160
62	0.7313	45.61	6.097
64	0.7238	45.14	6.034
66	0.7165	44.68	5.973
68	0.7093	44.23	5.913
70	0.7022	43.79	5.854
72	0.6953	43.36	5.797
74	0.6886	42.94	5.741
76	0.6819	42.53	5.685
78	0.6754	41.92	5.631
80	0.6690	41.72	5.577
82	0.6628	41.33	5.526
84	0.6566	40.95	5.474
86	0.6506	40.57	5.424
88	0.6446	40.20	5.374
90	0.6388	39.84	5.326
92	0.6331	39.48	5.278
94	0.6275	39.13	5.231
96	0.6220	38.79	5.186
98	0.6116	38.45	5.141
100	0.6112	38.12	5.096

FIGURE 11-28 A pump decal indicating that the diesel fuel is ultra-low-sulfur diesel (ULSD) and must be used in 2007 and newer diesel vehicles.

FREQUENTLY ASKED QUESTION

HOW CAN YOU TELL IF GASOLINE HAS BEEN ADDED TO THE DIESEL FUEL BY MISTAKE?

If gasoline has been accidentally added to diesel fuel and is burned in a diesel engine, the result can be very damaging to the engine. The gasoline can ignite faster than diesel fuel, which would tend to increase the temperature of combustion. This high temperature can harm injectors and glow plugs, as well as pistons, head gaskets, and other major diesel engine components. If contaminated fuel is suspected, first smell the fuel at the filler neck. If the fuel smells like gasoline, then the tank should be drained and refilled with diesel fuel. If the smell test does not indicate a gasoline smell (or any rancid smell), then test a sample for proper API gravity.

NOTE: Diesel fuel designed for on-road use should be green in color. Red diesel fuel (high sulfur) should only be found in off-road or farm equipment.

many more cars are equipped with diesel engines. Diesel engines manufactured to 2007 or newer standards must use ultra-low-sulfur diesel fuel containing less than 15 parts per million (PPM) of sulfur compared to the older low-sulfur specification of 500 PPM. The purpose of the lower sulfur amount in diesel fuel is to reduce emissions of sulfur oxides (SO_x) and particulate

FIGURE 11-29 Biodiesel is available at few locations.

matter (PM) from heavy-duty highway engines and vehicles that use diesel fuel. The emission controls used on 2007 and newer diesel engines require the use of **ultra-low-sulfur diesel (ULSD)** for reliable operation. See Figure 11-28.

Ultra-low-sulfur diesel (ULSD) will eventually replace the current highway diesel fuel, low-sulfur diesel, which can have as much as 500 PPM of sulfur. ULSD is required for use in all model year 2007 and newer diesel-powered highway vehicles. These vehicles are equipped with advanced emission control systems that are incompatible with low sulfur (500 PPM) fuel. ULSD looks lighter in color and has less smell than other diesel fuel.

BIODIESEL

Biodiesel is a domestically produced, renewable fuel that can be manufactured from vegetable oils, animal fats, or recycled restaurant greases. Biodiesel is safe, biodegradable, and reduces serious air pollutants such as particulate matter (PM), carbon monoxide, and hydrocarbons. Biodiesel is defined as mono-alkyl esters of long-chain fatty acids derived from vegetable oils or animal fats that conform to ASTM D6751 specifications for use in diesel engines. Biodiesel refers to the pure fuel before blending with diesel fuel. See Figure 11-29.

Biodiesel blends are denoted as "BXX" with "XX" representing the percentage of biodiesel contained in the blend (i.e., **B20** is 20% biodiesel, 80% petroleum diesel). Blends of 20% biodiesel with 80% petroleum diesel (B20) can generally be used in unmodified diesel engines; however, users should consult their OEM and engine warranty statement. Biodiesel can also be used in its pure form (B100), but it may require certain engine modifications to avoid maintenance and performance problems and may not be suitable for wintertime use. Users should consult their engine warranty statement for more information on fuel blends of greater than 20% biodiesel.

In general, B20 costs 30 to 40 cents more per gallon than conventional diesel. Although biodiesel costs more than regular diesel fuel, often called **petrodiesel,** fleet managers can make the switch to alternative fuels without purchasing new vehicles, acquiring new spare parts inventories, rebuilding refueling stations, or hiring new service technicians. Biodiesel has the following characteristics:

1. Purchasing biodiesel in bulk quantities decreases the cost of fuel.
2. Biodiesel maintains similar horsepower, torque, and fuel economy.
3. Biodiesel has a higher cetane number than conventional diesel, which increases the engine's performance.
4. Biodiesel has a high flash point and low volatility so it does not ignite as easily as petrodiesel, which increases the margin of safety in fuel handling. In fact, it degrades four times faster than petrodiesel and is not particularly soluble in water.
5. It is nontoxic, which makes it safe to handle, transport, and store. Maintenance requirements for B20 vehicles and petrodiesel vehicles are the same. B100 does pose a few concerns, however.
6. Biodiesel acts as a lubricant and this can add to the life of the fuel system components.

E-DIESEL FUEL

E-diesel, also called **diesohol** outside of the United States, is standard No. 2 diesel fuel that contains up to 15% ethanol. While E-diesel can have up to 15% ethanol by volume, typical blend levels are from 8% to 10%.

Cetane Rating

The higher the cetane number, the shorter the delay between injection and ignition. Normal diesel fuel has a cetane number of about 50. Adding 15% ethanol lowers the cetane number. To increase the cetane number back to that of conventional diesel fuel, a cetane-enhancing additive is added to E-diesel. The additive used to increase the cetane rating of E-diesel is ethylhexylnitrate or ditertbutyl peroxide.

The flash point is the minimum temperature at which the fuel will ignite (flash). E-diesel has a lower flash point than conventional diesel fuel (50°F instead of 126°F) and therefore is less safe to handle.

FREQUENTLY ASKED QUESTION

I THOUGHT BIODIESEL WAS VEGETABLE OIL?

Biodiesel is vegetable oil with the glycerin component removed by means of reacting the vegetable oil with a catalyst. The resulting hydrocarbon esters are 16 to 18 carbon atoms in length, almost identical to the petroleum diesel fuel atoms. This allows the use of biodiesel fuel in a diesel engine with no modifications needed. Biodiesel powered vehicles do not *need* a second fuel tank, whereas vegetable-oil-powered vehicles do.

There are three main types of fuel used in diesel engines. These are:

- Petroleum diesel, a fossil hydrocarbon with a carbon chain length of about 16 carbon atoms.
- Biodiesel, a hydrocarbon with a carbon chain length of 16 to 18 carbon atoms.
- Vegetable oil is a triglyceride with a glycerin component joining three hydrocarbon chains of 16 to 18 carbon atoms each, called straight vegetable oil (SVO). Other terms used when describing vegetable oil include:
  - **Pure plant oil (PPO)**—a term most often used in Europe to describe **SVO**
  - **Waste vegetable oil (WVO)**—this oil could include animal or fish oils from cooking
  - **Used cooking oil (UCO)**—a term used when the oil may or may not be pure vegetable oil

  Vegetable oil is not liquid enough at common ambient temperatures for use in a diesel engine fuel delivery system designed for the lower-viscosity petroleum diesel fuel. Vegetable oil needs to be heated to obtain a similar viscosity to biodiesel and petroleum diesel. This means that a heat source needs to be provided before the fuel can be used in a diesel engine. This is achieved by starting on petroleum diesel or biodiesel fuel until the engine heat can be used to sufficiently warm a tank containing the vegetable oil. It also requires purging the fuel system of vegetable oil with petroleum diesel or biodiesel fuel prior to stopping the engine to avoid the vegetable oil thickening and solidifying in the fuel system away from the heated tank. The use of vegetable oil in its natural state does, however, eliminate the need to remove the glycerin component.

Many vehicle and diesel engine fuel system suppliers permit the use of biodiesel fuel that is certified as meeting testing standards. None permit the use of vegetable oil in its natural state.

NOTE: For additional information on biodiesel and the locations where it can be purchased, visit *www.biodiesel.org*.

FREQUENTLY ASKED QUESTION

HOW LONG CAN OXYGENATED FUEL BE STORED BEFORE ALL OF THE OXYGEN ESCAPES?

The oxygen in oxygenated fuels, such as E10, E85, and E-diesel, is not in a gaseous state like the CO_2 in soft drinks. The oxygen is part of the molecule of ethanol or other oxygenates and does not bubble out of the fuel. Oxygenated fuels, just like any fuel, have a shelf life of about 90 days.

E-diesel has better cold-flow properties than conventional diesel. The heat content of E-diesel is about 6% less than conventional diesel, but the particulate matter (PM) emissions are reduced by as much as 40%, 20% less carbon monoxide, and a 5% reduction in oxides of nitrogen (NO_X).

Currently, E-diesel is considered to be experimental and can be used legally in off-road applications or in mass-transit buses with EPA approval. For additional information, visit *www.e-diesel.org*.

SYNTHETIC FUELS

Synthetic fuels were first developed using the Fischer-Tropsch method and have been in use since the 1920s to convert coal, natural gas, and other fossil fuel products into a fuel that is high in quality and clean-burning. The process for producing Fischer-Tropsch fuels was patented by two German scientists, Franz Fischer and Hans Tropsch, during World War I. The Fischer-Tropsch method uses carbon monoxide and hydrogen (the same synthesis gas used to produce hydrogen fuel) to convert coal and other hydrocarbons to liquid fuels in a process similar to hydrogenation, another method for hydrocarbon conversion. The process using natural gas, also called **gas-to-liquid (GTL)** technology, uses a catalyst, usually iron or cobalt, and incorporates steam reforming to give off the by-products of carbon dioxide, hydrogen, and carbon monoxide.

Whereas traditional fuels emit environmentally harmful particulates and chemicals, namely sulfur compounds, Fischer-Tropsch fuels combust with no soot or odors and emit only low levels of toxins. Fischer-Tropsch fuels can also be blended with traditional transportation fuels with little equipment modification, as they use the same engine and equipment technology as traditional fuels.

The fuels contain a very low sulfur and aromatic content and they produce virtually no particulate emissions. Researchers also expect reductions in hydrocarbon and carbon monoxide emissions. Fischer-Tropsch fuels do not differ in fuel performance from gasoline and diesel. At present, Fischer-Tropsch fuels are very expensive to produce on a large scale, although research is under way to lower processing costs. However, some synthetic diesel fuel is currently being used in South Africa. Diesel fuel created using the **Fischer-Tropsch Diesel** (**FTD**) process is often called GTL diesel. GTL diesel can also be combined with petroleum diesel to produce a GTL blend. This fuel product is currently being sold in Europe, and plans are in place to introduce it in North America.

Coal to Liquid (CTL)

Coal is very abundant in the United States and coal can be converted to a liquid fuel through a process called **coal to liquid (CTL)**. The huge cost is the main obstacle to these plants. The need to invest $1.4 billion per plant before it can make any product is the reason no one has built a CTL plant yet in the United States. Investors need to be convinced that the cost of oil is going to remain high in order to get them to commit this kind of money.

A large plant might be able to produce 120,000 barrels of liquid fuel a day and would consume about 50,000 tons of coal per day. However, such a plant would create about 6,000 tons of CO_2 per day. These CO_2 emissions and the cost involved make CTL a new technology that is not likely to expand.

Two procedures can be used to convert coal-to-liquid fuel:

1. **Direct**—In the direct method, coal is broken down to create liquid products. First the coal is reacted with hydrogen (H_2) at high temperatures and pressure with a catalyst. This process creates a synthetic crude, called syncrude, which is then refined to produce gasoline or diesel fuel.
2. **Indirect**—In the indirect method, coal is first turned into a gas and the molecules are reassembled to create the desired product. This process involves turning coal into a gas called syn-gas. The syn-gas is then converted into liquid, using the Fischer-Tropsch (FT) process.

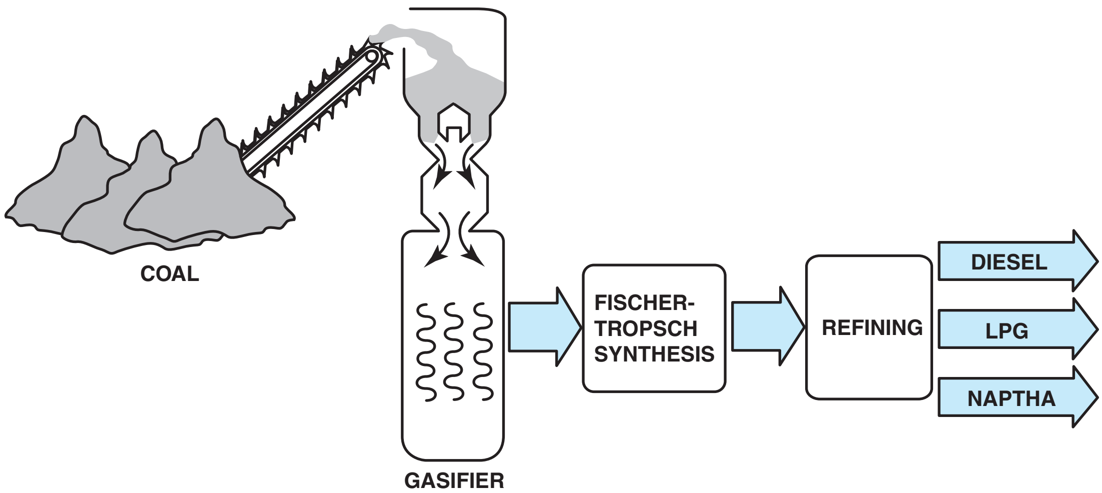

FIGURE 11-30 A typical coal-to-liquid plant.

Russia has been using CTL by injecting air into the underground coal seams. Ignition is provided and the resulting gases are trapped and converted to liquid gasoline and diesel fuel through the Fischer-Tropsch process. This underground method is called **underground coal gasification (UCG).** See Figure 11-30.

Methanol to Gasoline

Exxon Mobil has developed a process for converting methanol (methyl alcohol) into gasoline in a process called **methanol-to-gasoline (MTG).** The MTG process was discovered by accident when a gasoline additive made from methanol was being created. The process instead created olefins (alkenes), paraffins (alkenes), and aromatic compounds, which in combination are known as gasoline. The process uses a catalyst and is currently being produced in New Zealand.

Future of Synthetic Fuels

Producing gasoline and diesel fuels by other methods besides refining from crude oil has usually been more expensive. With the increasing cost of crude oil, alternative methods are now becoming economically feasible. Whether or not the diesel fuel or gasoline is created from coal, natural gas, or methanol, or created by refining crude oil, the transportation and service pumps are already in place. Compared to using compressed natural gas or other similar alternative fuels, synthetic fuels represent the lowest cost.

SAFETY PROCEDURES WHEN WORKING WITH ALTERNATIVE-FUEL VEHICLES

All fuels are flammable and many are explosive under certain conditions. Whenever working around compressed gases of any kind (CNG, LNG, propane, or LPG), always wear personal protective equipment (PPE), including at least the following items:

1. Safety glasses and/or face shield.
2. Protective gloves.
3. Long-sleeve shirt and pants to help protect bare skin from the freezing effects of gases under pressure in the event that the pressure is lost.
4. If any fuel gets on the skin, the area should be washed immediately.
5. If fuel spills on clothing, change into clean clothing as soon as possible.
6. If fuel spills on a painted surface, flush the surface with water and air dry. If simply wiped off with a dry cloth, the paint surface could be permanently damaged.
7. As with any fuel-burning vehicle, always vent the exhaust to the outside. If methanol fuel is used, the exhaust contains formaldehyde, which has a sharp odor and can cause severe burning of the eyes, nose, and throat.

WARNING: **Do not smoke or have an open flame in the area when working around or refueling any vehicle.**

TESTING FOR ALCOHOL CONTENT IN GASOLINE Step-by-Step

STEP 1 A fuel composition tester is the recommended tool to use to test the alcohol content of gasoline.

STEP 2 This battery-powered tester uses light-emitting diodes (LEDs), meter lead terminals, and two small openings for the fuel sample.

STEP 3 The first step is to verify the proper operation of the tester by measuring the air frequency by selecting AC hertz on the meter. The air frequency should be between 35 Hz and 48 Hz.

STEP 4 After verifying that the tester is capable of correctly reading the air frequency, gasoline is poured into the testing cell of the tool.

STEP 5 Record the AC frequency as shown on the meter and subtract 50 from the reading (e.g., 60.50 − 50.00 = 10.5). This number (10.5) is the percentage of alcohol in the gasoline sample.

STEP 6 Adding additional amounts of ethyl alcohol (ethanol) increases the frequency reading.

SUMMARY

1. Gasoline is a complex blend of hydrocarbons. Gasoline is blended for seasonal usage to achieve the correct volatility for easy starting and maximum fuel economy under all driving conditions.
2. Winter-blend fuel used in a vehicle during warm weather can cause a rough idle and stalling because of its higher Reid vapor pressure (RVP).
3. Abnormal combustion (also called detonation or spark knock) increases both the temperature and the pressure inside the combustion chamber.
4. Most regular-grade gasoline today, using the $(R + M) \div 2$ rating method, is 87 octane; midgrade (plus) is 89 and premium grade is 91 or higher.
5. Oxygenated fuels contain oxygen to lower CO exhaust emissions.
6. Gasoline should always be purchased from a busy station, and the tank should not be overfilled.
7. Flexible fuel vehicles are designed to operate on gasoline or gasoline-ethanol blends up to 85% ethanol.

REVIEW QUESTIONS

1. What is the difference between summer-blend and winter-blend gasoline?
2. What is Reid vapor pressure?
3. What is vapor lock?
4. What does the $(R + M) = 2$ gasoline pump octane rating indicate?
5. What are five octane improvers that may be used during the refining process?
6. What is stoichiometric?

CHAPTER QUIZ

1. Winter-blend gasoline _________.
   - **a.** Vaporizes more easily than summer-blend gasoline
   - **b.** Has a higher RVP
   - **c.** Can cause engine driveability problems if used during warm weather
   - **d.** All of the above
2. Vapor lock can occur _________.
   - **a.** As a result of excessive heat near fuel lines
   - **b.** If a fuel line is restricted
   - **c.** During both a and b
   - **d.** During neither a nor b
3. Technician A says that spark knock, ping, and detonation are different names for abnormal combustion. Technician B says that any abnormal combustion raises the temperature and pressure inside the combustion chamber and can cause severe engine damage. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both technicians A and B
   - **d.** Neither technician A nor B
4. Technician A says that the research octane number is higher than the motor octane number. Technician B says that the octane rating posted on fuel pumps is an average of the two ratings. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both technicians A and B
   - **d.** Neither technician A nor B
5. Technician A says that in going to high altitudes, engines produce lower power. Technician B says that most engine control systems can compensate the air–fuel mixture for changes in altitude. Which technician is correct?
   - **a.** Technician A only
   - **b.** Technician B only
   - **c.** Both technicians A and B
   - **d.** Neither technician A nor B

6. When refueling a CNG vehicle, why is it recommended that the tank be filled to a high pressure?
   a. The range of the vehicle is increased
   b. The cost of the fuel is lower
   c. Less of the fuel is lost to evaporation
   d. Both a and c
7. The use of premium high-octane gasoline in an engine designed to use regular-grade gasoline will increase engine power.
   a. True
   b. False
8. To avoid problems with the variation of gasoline, all government testing uses _________ as a fuel during testing procedures.
   a. MTBE (methyl tertiary butyl ether)
   b. Indolene
   c. Xylene
   d. TBA (tertiary butyl alcohol)
9. Avoid topping off the fuel tank because _________.
   a. It can saturate the charcoal canister
   b. The extra fuel simply spills onto the ground
   c. The extra fuel increases vehicle weight and reduces performance
   d. The extra fuel goes into the expansion area of the tank and is not used by the engine
10. Using ethanol-enhanced or reformulated gasoline can result in reduced fuel economy.
   a. True
   b. False