Vocabulary

aerobic fermentation	catalyst	ethanol	natural gas
alcohol	catalytic cracking	feedstock	octane rating
alternative fuel	compressed natural gas	fuel injector	olefins
alternative-fuel vehicle	denatured alcohol	gasohol	paraffins
anaerobic fermentation	distillation	hydrogen	propane
aromatics	E85	liquefied natural gas	rapeseed
biodiesel	electrolysis	M85	residual oil
by-product	Energy Policy Act of 1992	M100	transesterification
carburetor	esters	methanol	wood alcohol

When you hear the term "**alternative fuels**," chances are good that it really means "alternative transportation fuels," because using clean fuels in motor vehicles is of interest today. From here on we will use the terms interchangeably to discuss biodiesel, ethanol, hydrogen, methanol, natural gas, and propane used in **alternative-fuel vehicles**. Some of these fuels also have significant non-transportation applications, which will be highlighted in the text.

FYI

What's in a Name?

EPACT

Defining alternative fuels is a political exercise. In 1995, the Texas Legislature decided that any fuel, including special gasoline called reformulated gasoline (RFG), that could meet certain emissions standards when used in vehicles could be considered an alternative fuel. This definition differs from that of the federal **Energy Policy Act of 1992 (EPACT)**, which excludes fuels derived solely from petroleum from the alternative fuels category.

EPACT's official definition of an alternative fuel is: "Methanol, denatured ethanol, and other alcohols; mixtures containing 85% or more by volume of methanol, denatured ethanol, and other alcohols with gasoline or other fuels; natural gas; liquefied petroleum gas; hydrogen; coal-derived liquid fuels; fuels (other than alcohol) derived from biological material; and electricity."

Electricity is included in the EPACT definition, even though it is a secondary energy source. If an electric-motor vehicle is powered by a device called a fuel cell, the categorizations are even trickier.

In a fuel cell, the elements hydrogen and oxygen combine to produce electrical energy to power a motor. The by-product is water.

Currently, the problem that makes fuel cell technology impractical for wide use is providing the fuel—pure hydrogen. Hydrogen can be produced from water, but it is expensive to do that. In addition, storing sufficient hydrogen on board a vehicle is difficult, because it is a highly diffuse gas. For more information on fuel cells, see unit 3, section 3.

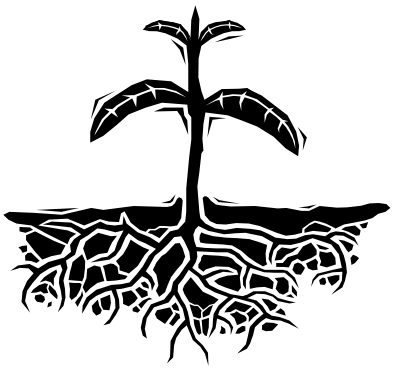


Figure 2-3-1
Soybean plant
Oil extracted from soybeans can be converted into biodiesel.

Alternative fuels provide three advantages over conventional fuels:

1. Using domestically produced transportation fuels can reduce U.S. dependence on imported crude oil.
2. Alternative fuels can reduce the amount of airborne pollution.
3. Cleaner-burning alternative fuels can allow less frequent engine maintenance or extend engine life.

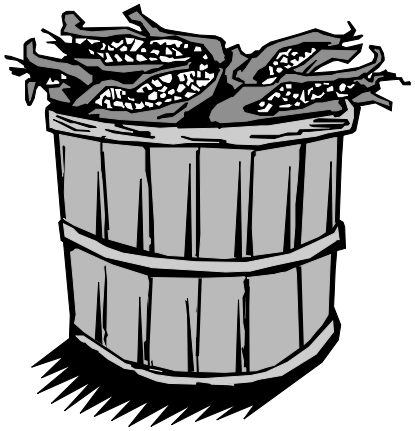


Figure 2-3-2 One bushel of corn
A typical bushel of corn weighs 56 pounds. Most of the weight is the starch, oil, protein, and fiber, and some is natural moisture. What can be extracted from a bushel of corn?

31.5 pounds of starch **or** 33.0 pounds of sweetener

or

2.5 gallons of fuel ethanol
12.4 pounds of 21% protein feed
3.0 pounds of 60% gluten meal
and 1.5 pounds of corn oil

Biodiesel

Biodiesel is derived from vegetable oils in an inexpensive process called **transesterification**, in which vegetable oil reacts with methanol or ethanol in the presence of a **catalyst**. The catalyst is used to speed up the reaction. The process yields about 96 percent biodiesel.

Many vegetable oils, both those used as foods and those unsuited for human consumption, can produce oil for biodiesel. The most economical choice depends on the oil yield per acre, product quality, the value of the wastes and **by-products** of the transesterification process, geography, and government policies. Soybean oil is currently the main source of biodiesel, but considerable interest has been shown in **rapeseed** oil because of its high oil yield and the value of its by-products as livestock feed.

Biodiesel has physical properties similar to diesel. Emissions properties, however, are better for biodiesel than for petroleum diesel. High crude oil prices and diminishing U.S. fossil-fuel resources could make manufacturing diesel from vegetable oils more attractive economically.

Ethanol

Ethyl **alcohol (ethanol)** has long been used as a fuel. One version of Henry Ford's Model T was designed to run on ethanol.

Ethanol can be made from many different sources of starches or sugars. By far the greatest amount of ethanol worldwide is made from sugar cane.

Conversion of sugar cane to ethanol:

$$C_{12}H_{22}O_{11} + H_2O \rightarrow 2C_6H_{12}O_6$$

sucrose + water → dextrose

then...

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

dextrose → ethanol + carbon dioxide

The world's leading ethanol producer is Brazil, where billions of gallons of fuel ethanol are produced from sugar cane each year.

In the United States, the price of sugar is too high to produce ethanol economically, so other sources are used. Corn is used to produce well over 90 percent of U.S. ethanol. Most U.S. ethanol is used to make **gasohol** (a mixture of 90 percent unleaded gasoline and 10 percent ethanol) and other blends to meet oxygenated-gasoline requirements. Ethanol used in these blends does not meet the federal definition of an alternative fuel. The blend burns cleaner, but it evaporates more readily, also.

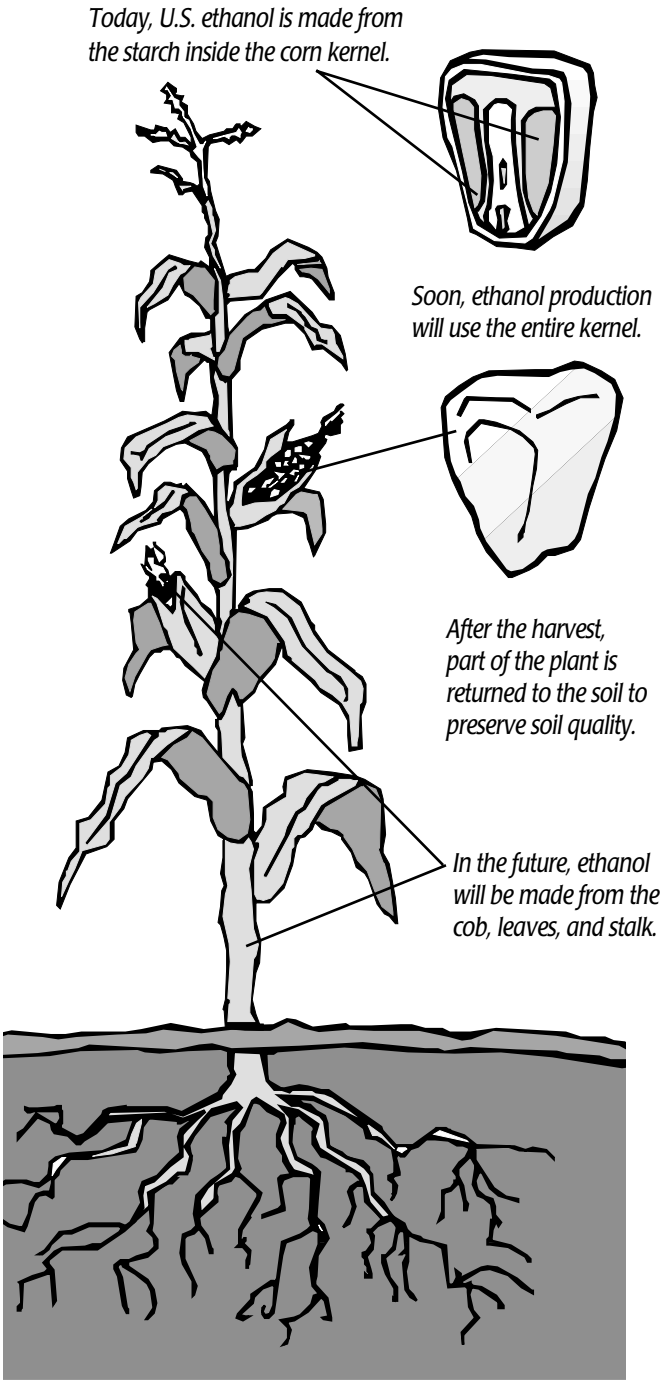


Figure 2-3-3 Corn-derived ethanol

As an alternative fuel, ethanol is generally blended with 15 percent gasoline to make **E85**, but in some vehicles straight ethanol (E100) can be used. In such cases, substances such as methanol are added to ethanol to **denature** it, or make it unfit for drinking. Denaturing also allows ethanol manufacturers to bypass alcoholic beverage taxes and regulation.

Making enough ethanol to meet a large part of our transportation fuel needs would take vast amounts of grain. About 57 million bushels of corn were made into 1.4 billion gallons of ethanol fuel in the United States in 1998. This represented 1.2 percent of the approximately 120 billion gallons of gasoline consumed that year.

Figure 2-3-4
Hydrogen, the simplest and most abundant element in the universe, holds great promise as a fuel.

Hydrogen

Hydrogen is produced from water through **electrolysis**, but it can also be processed from other hydrocarbon fuels and biomass sources. Hydrogen is an efficient energy source with high energy content that produces few emissions.

Though some automakers are testing hydrogen-burning cars, they are currently not feasible or economical. Possibly the greatest potential use for hydrogen as a transportation fuel is when used in a fuel cell to generate electricity to power a vehicle. For more information on fuel cells see unit 3, section 3.

Figure 2-3-5 *Most of the 10.1 billion pounds of methanol produced yearly in the United States is used as a raw material to make other products such as ammonia.*

Methanol

Methanol, or methyl alcohol, is a colorless, odorless liquid. In the United States, it is most commonly used as a chemical feedstock, solvent, or to produce the gasoline additive methyl tertiary butyl ether (MTBE). Methanol can be used straight (**M100**) as a gasoline or diesel substitute or blended with 15 percent gasoline (**M85**).

In 2000, U.S. industry produced 10.1 billion pounds of methanol. 3.2 billion pounds was consumed as MTBE and transportation fuel. The rest went to non-transportation uses.

Most methanol produced in the United States is made from natural gas. To make methanol, natural gas is reacted with a catalyst at high temperatures and

pressures. Methanol can also be made from coal, **residual oil**, and high-cellulose biomass. (A common name for methanol is **wood alcohol**, because wood used to be its primary source.) All these feedstocks are subjected to gasification (see "syngas") and then made into methanol the same way natural gas is.

Methanol has generally low overall emissions compared to gasoline and is therefore referred to as a clean-burning fuel. Methanol contains seventy-three percent as much energy as gasoline per unit volume. But because methanol burns more completely than gasoline, the actual amount of energy that can be extracted per unit volume is sixty percent that of gasoline. More complete combustion also lowers emissions because, there is less carbon dioxide and water left over after combustion. However, methanol's lower Btu reduces the range a vehicle can travel on an equivalent tank of fuel.

Combustion of methanol

$$2CH_3OH + 3O_2 \rightarrow 4H_2O + 2CO_2$$

Combustion of gasoline (octane)

$$C_8H_{18} + 25O_2 \rightarrow 8CO_2 + 9H_2O$$

Natural Gas

Natural gas, a fossil fuel, is a mixture of hydrocarbons, mostly methane. Texas alone produces 28 percent of U.S. natural gas, and Louisiana and Oklahoma combined produce another 29 percent. Natural gas is widely used in stationary applications such as heating and electric generation.

Interest in natural gas as a transportation fuel stems mainly from its clean-burning qualities, its domestic origin, and its commercial availability. It is cleaner burning than gasoline or diesel. Natural gas is also lower in sulfur compounds than conventional fuels, and it emits fewer particulates into the air when it is burned.

Natural gas can be used in any vehicle with an internal-combustion engine, although the vehicle must be outfitted with a special **carburetor** or **fuel injector** and fuel tanks. Natural gas costs less than gasoline and has a higher **octane rating**. More than 90,000 cars, trucks, and buses run on natural gas in the United States.

Figure 2-3-6 *LNG is made by cooling natural gas to a temperature of -259ºF. At that temperature, its volume is reduced 615 times. A car reduced 615 times would fit on your thumbnail.*

Because of its gaseous nature, natural gas must be compressed or liquefied to be efficiently stored on board a vehicle. **Compressed natural gas (CNG)** tanks have to be refilled more often than gasoline tanks, and there are few refueling stations.

Liquefied natural gas (LNG) is made by cooling natural gas to a temperature of -259ºC. At that temperature, natural gas becomes a liquid, and its volume is reduced 615 times, which makes it easier to store and transport.

Propane

Propane is one of the fossil fuels in liquefied petroleum (LP) gas. **Liquefied petroleum gas** consists mainly of propane, propylene, butane, and butylene in various mixtures. In the United States, the mixture is mostly propane and is sold under that name. Propane is widely used for heating, cooking, and in industry as a raw material for chemical manufacturing.

Propane comes from natural gas and petroleum. Despite the "liquefied petroleum" name, roughly two-thirds of the propane used in the United States is extracted from raw natural gas. (Raw natural gas is natural gas that hasn't been cleaned and processed yet.) Raw natural gas contains about 92 percent methane, and most of the rest is a mixture of ethane and the "LP" gases. Propane is separated from natural gas at a natural gas processing plant (Figure 1-2-7).

The other one-third of U.S. propane is extracted from petroleum. Like its close chemical relative methane, propane is colorless and odorless. As with methane, an odorant is added to propane for safety reasons, to help identify leaks.

Propane combines many of the storage and transportation advantages of a liquid with the fuel advantages of a gas. Under normal atmospheric pressure and temperature, it is a gas. Under moderate pressure, however, propane changes into a liquid. Propane is 270 times more compact in its liquid state than it is as a gas. Liquid propane rapidly vaporizes into a gas when it is released from its tank to fuel vehicles or other equipment.

Propane has been used as a transportation fuel for more than half a century. Many taxicab companies, government agencies and school districts have converted their fleets to propane. Today about 300,000 U.S. vehicles use propane.

Like natural gas, propane is clean-burning, leaving no deposits that speed up engine wear. This means less maintenance and a longer engine life. Because propane is a low-pollution fuel, forklift trucks powered by propane can be operated safely inside factories and warehouses.

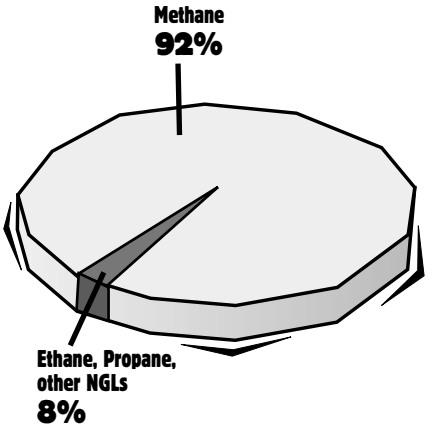


Figure 2-3-7 *Raw natural gas contains about 92 percent "dry" gas (methane,). The rest is known as natural gas liquids or NGLs, including the LP gases ethane, propane, and butane.*

Combustion of propane

$$CH_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$$

Octane Ratings of Fuels

Octane is the name of a compound in the alkane series (see unit 2, section 1) that has eight carbon atoms (C_8H_{18}). Octane is one of many hydrocarbon compounds present in gasoline.

A fuel's octane rating is a measure of its ability to resist catching on fire too soon while it is being compressed and heated in the cylinders of an internal-combustion engine. Octane ratings are sometimes called "anti-knock" ratings, because engines knock loudly when their fuel-air mixtures ignite too early. The higher a fuel's octane number, the more resistant it is to pre-ignition, and the higher the engine's compression ratio can be.

Pure octane has an octane rating of 100. Following are some typical octane ratings of motor fuels:

Gasoline	87 to 93
Methanol	100
Ethanol	100
Propane	104
Natural Gas	120+

Source: *U.S. Department of Energy*

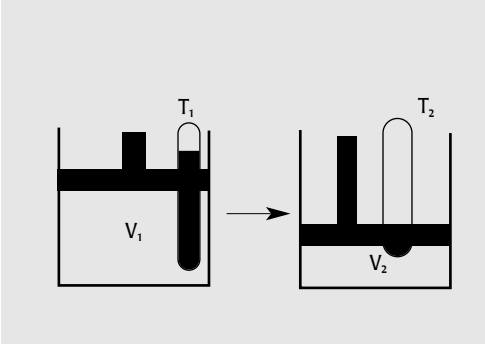
Charles's gas law

The volume of a fixed mass of gas at a constant pressure varies directly with absolute temperature.

The behavior of gases can be examined by looking at Charles's gas law, which says the volume of a fixed mass of gas at a constant pressure varies directly with absolute temperature. This means that as the temperature of a gas is lowered the molecules move closer together and the volume of the gas decreases proportionate to the drop in temperature. Think about blowing up a balloon indoors and then taking it outside on a cold day. The balloon would get smaller, because the air (gas) inside will shrink in volume. What would happen if you brought the balloon back inside?

Charles's gas law:

$$\frac{V_1}{T_1} \rightarrow \frac{V_2}{T_2}$$



V = volume
T = absolute temperature

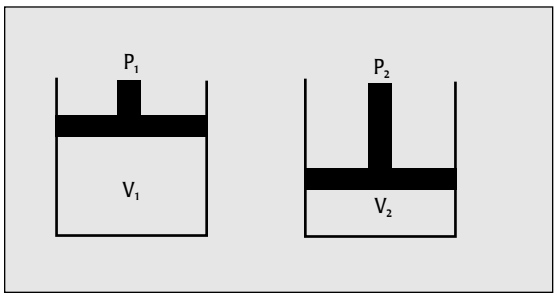
Boyle's Law

Boyle's gas law complements Charles's gas law. Boyle's law states that when the temperature is held constant, the volume of a fixed mass of gas in a container varies inversely with the pressure. In other words, as long as the temperature of a gas such as propane doesn't change as the pressure is increased, the volume of the gas will decrease, and vice versa. Another example is the helium gas used to blow up balloons. A small helium gas tank can hold a large amount of gas under pressure.

When the temperature is held constant, the volume of a fixed mass of gas in a container varies inversely with the pressure.

Boyle's gas law

$$P_1 \times V_1 = P_2 \times V_2$$



P = pressure
V = volume

What Are Alternative Fuels? Resource List

www.afdc.nrel.gov/
Alternative Fuels Data Center, U.S. Department of Energy
Statistics and other information about alternative fuels, alternative fuel vehicles, and alternative fuel refueling locations.

www.transportationtech.com/Resources/pdfs/afv99.pdf
Miramar College, San Diego, California
A 24-page introductory workbook on alternative fuels and alternative fuel vehicles.

www.ott.doe.gov/technologies.shtml
Office of Transportation Technologies, U.S. Department of Energy
Surveys current technologies and research on alternative fuel, hybrid and electric vehicles. The site includes a children's page on alternative fuels, the environment and student competitions.

www.rrc.state.tx.us
Railroad Commission of Texas
The Railroad Commission is Texas' chief energy agency. The site's Education and Training link has downloadable lessons from *Alternative Energy*, a list of 1,200 propane refueling locations, and information about propane as an environmentally beneficial alternative fuel.

http://www.pprc.org/pprc/pubs/topics/altfuels.html
Pacific Northwest Pollution Prevention Resource Center, Seattle
Report on "Alternative Fuels for Fleet Vehicles" includes a resource list of web sites on alternative energy with descriptions, comments and contacts.

www.npga.org
National Propane Gas Association
Information about propane, propane vehicles, propane and the environment.

www.ngvc.org
Natural Gas Vehicle Coalition
Information about natural gas, natural gas vehicles, natural gas and the environment.

www.methanol.org
American Methanol Institute
Information about methanol and reformulated gasoline; methanol and the environment.

www.ethanol.org
American Coalition for Ethanol
Information about ethanol fuels, ethanol vehicles, ethanol and the environment.

www.ttcorp.com/nha/index.htm
National Hydrogen Association
Information about a hydrogen energy economy; includes a source book of hydrogen applications.

www.biomass.org
American Bioenergy Association
Fact sheets on the economic and environmental potential of converting organic materials to energy.