Light-Duty Natural Gas Vehicles

Instructor's Manual

National Alternative Fuels Training Consortium

A Program of West Virginia University

Notes.

Energy Density

While the **energy content** of a fuel denotes the amount of energy for a given **weight** of fuel, the **energy density** denotes the amount of energy (Btu or kilojoules) for a given **volume** (ft^3 or m^3) of fuel. Thus, energy density is the product of the energy content (LHV in our case) and the density of a given fuel.

Energy density is really a measure of how compactly hydrogen atoms are packed in a fuel. Hydrocarbons of increasing complexity (those with more and more hydrogen atoms per molecule), therefore, have increasing energy density. At the same time, hydrocarbons of increasing complexity have an increasing number of carbon atoms in each molecule, resulting in fuels that are heavier in absolute terms.

On this basis, methane's energy density is poor when compared to diesel, since methane has such low density. Yet its energy-to-weight ratio is the best of all hydrocarbon fuels, because it is so light.

> Hydrogen has the highest energy-to-weight ratio of any fuel because hydrogen is the lightest element and has no heavy carbon atoms. It is for this reason that hydrogen has been used extensively in the space program, where weight is a critical factor.

The energy densities of comparative fuels, based on the LHV, are indicated in Table 6–7.

Fuel	Energy Density (LHV):	Btu/ft^3	kJ/m^3
Hydrogen	as a gas at 1 atm and 60°F (15°C):	270	10,050
	as a gas at 3000 psig (200 barg) and 60°F (15°C):	48,900	1,825,000
	as a gas at 10,000 psig (690 barg) and 60°F (15°C):	21,000	4,500,000
	as a liquid:	227,850	8,491,000
Methane	as a gas at 1 atm and 60°F (15°C):	875	32,560
	as a gas at 3000 psig (200 barg) and 60°F (15°C):	184,100	6,860,300
	as a liquid:	561,500	20,920,400
Propane	as a gas at 1 atm and 60°F (15°C):	2,325	86,670
	as a liquid:	630,400	22,488,800
Gasoline	as a liquid:	836,000	31,150,000
For comparison, the energy density of a lead acid battery is approximately 8,700 Btu/ft^3 (324,000 kJ/m^3).			

Table 6-7: Energy densities of various fuels.

The energy density of a fuel is also affected by whether the fuel is stored as a liquid or as a gas, and if as a gas, at what pressure. To put it into perspective:

> A 132-gallon (500-liter) diesel tank containing 880 lb (400 kg) of fuel is equivalent on an energy basis to approximately a 635-gallon (2,403-liter) volume of methane gas at 3600 psig (250 barg). This is a 4.8 times increase in volume, although the weight of the methane is approximately 724 lb (329 kg), which represents a decrease in fuel weight of about 18%.Because LNG is a liquid, it only requires a 233-gallon (885 liter) tank to match the 132-gallon diesel tank. This represents a 1.8 times increase in volume.

With regard to LNG leaks, very cold methane becomes buoyant soon after it evaporates. LNG leaks evaporate fairly quickly because its boiling point is low. Generally, liquid leaks are visible as frost. However, **frost formed over tank valves does not always mean there is a leak**.

The outside of the LNG tank should be at ambient temperature (the same as the surrounding environment). If frost forms on the outer shell, it indicates that the vacuum insulation of the tank has failed and requires repair. It is normal, however, for frost to form around the tank head plumbing (primarily the LIQUID OUT piping) when a vehicle is operating and consuming fuel, as shown in Figure 6-13. LNG vehicular fuel systems generally employ dedicated leak detection equipment; the same is the case for maintenance facilities.

CNG leaks can only be accurately detected by using a combustible gas leak detector or leak detection soap designed for combustible hydrocarbons, as shown in Figure 6-14.

In contrast to methane, gasoline and diesel vapors have specific gravities greater than that of air, so they spread laterally and evaporate slowly, resulting in a widespread, lingering fire hazard. Propane gas is also denser than air, so it accumulates in low spots and disperses slowly, resulting in a protracted fire or explosion hazard. Heavy vapors can also form vapor clouds or plumes that travel as they are pushed by breezes.

> ***CAUTION: In a closed room, concentrations of any fuel can be significant. Always ensure that there is adequate ventilation and an emergency exhaust system.***

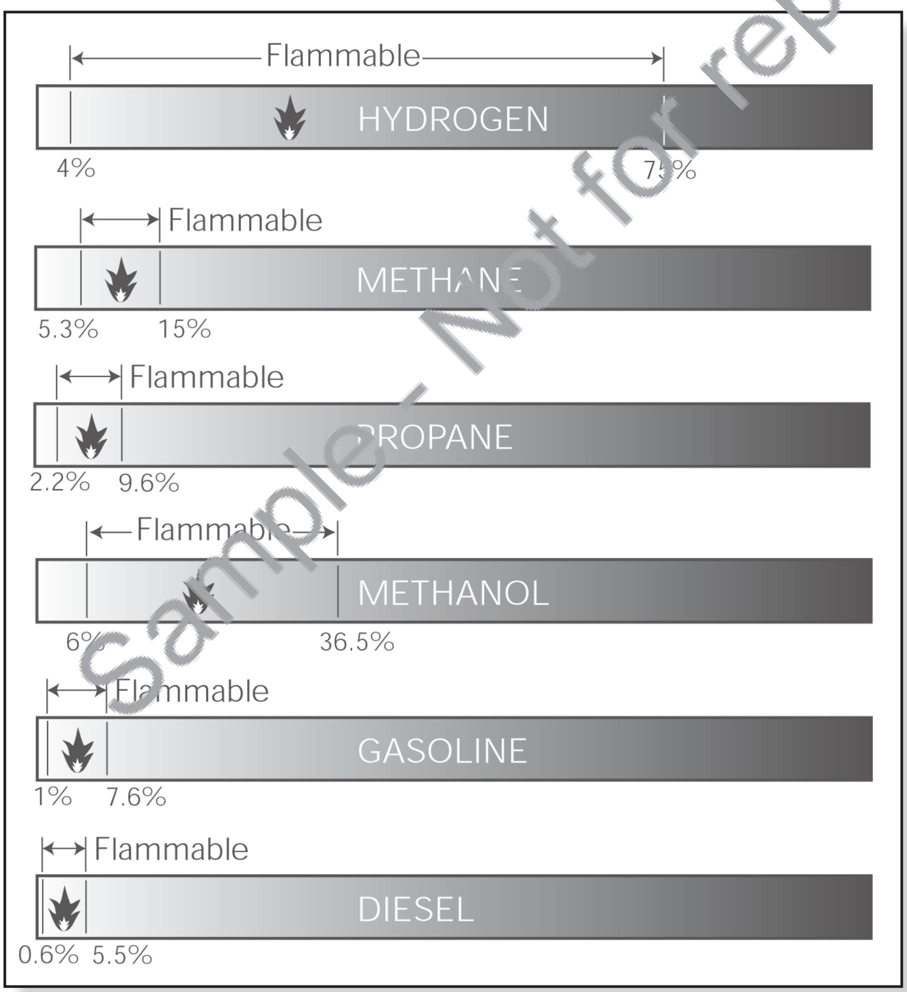


Figure 6-12: Flammability ranges of various fuels at STP.

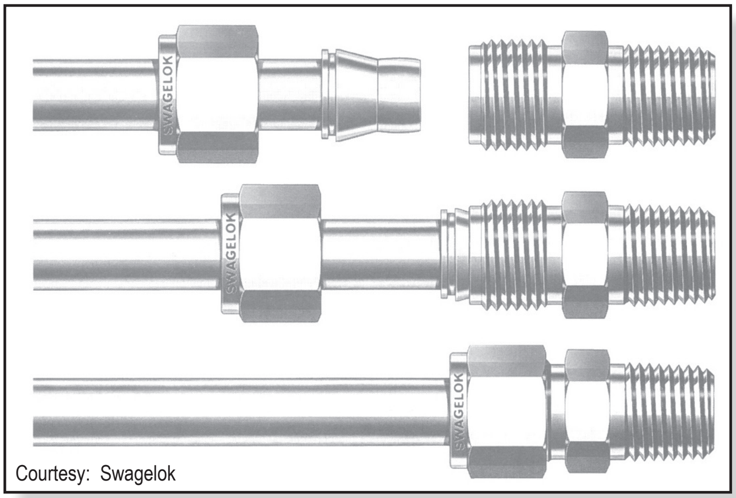


Figure 8-13E: Example of fitting tightening procedure.

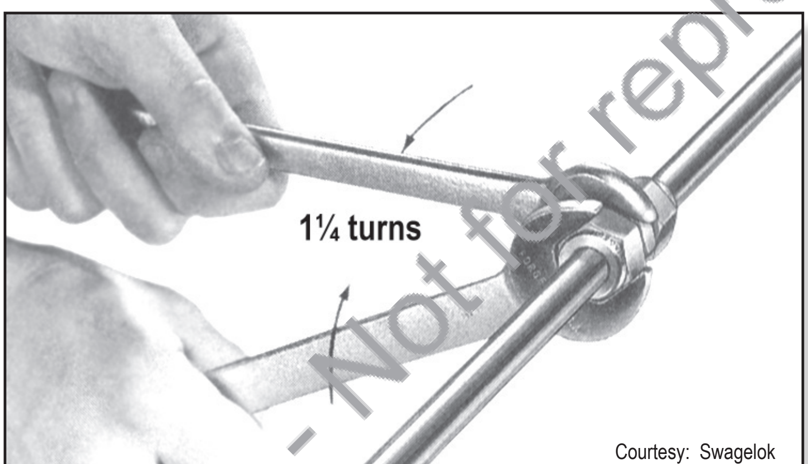


Figure 8-13F: Example of using back-up wrench on fitting make-up.

Manual Shutoff Valves

To meet the requirements of NFPA 52, every CNG system must have a shutoff valve:

> "**6.6.2** …a manual shutoff valve or a normally-closed, automatically-actuated shutoff valve shall be installed that allows isolation of the container(s) from the remainder of the fuel system. Where a manual shutoff valve is used, it shall be in an accessible location and shall have not more than 90 degrees rotation from the open to the closed positions. Access to the manual shutoff valve shall not require the use of any key or tool."

Manual shutoff valves (also commonly referred to as **quarter-turn (1/4) valves**) are typically ball-type valves with an internal configuration very similar to that of a cylinder valve.

The manual shutoff valve must be placed in a location easily accessible to the operator and must be clearly marked. In most cases, the valve is installed inside the vehicle operator's door, near the high-pressure regulator (HPR) or elsewhere; and it must be clearly marked "Manual Shutoff Valve".

Pressure Drop Test

If a CNG cylinder leak is suspected, a pressure drop test will help determine whether a decrease in temperature is creating a normal pressure drop or if a leak is contributing to the pressure drop.

For example:

If the temperature change is not too large, you can use the following formula.

$$P1 \div T1 = P2 \div T2$$

Where:
P1 = initial absolute pressure
T1 = initial absolute temperature
P2 = final absolute pressure
T2 = final absolute temperature

Absolute pressure = gauge pressure + atmospheric pressure
Absolute temperature = °F + 459 = °R

If initial test readings show 2000 psig at 70°F and 12 hours later test readings are 1,950 psig at 65°F then,

P1 = 2,000 psig + 14.7 psia = 2,014.7 psia
T1 = 70°F + 459 = 529°R
P1 ÷ T1 = 2,014.7 ÷ 529 = 3.8
P2 = 1,950 psig + 14.7 psia = 1,964.7 psia
T2 = 65°F + 459 = 524°R
P2 ÷ T2 = 1,964.7 ÷ 524 = 3.7

So, within the limits of measuring accuracy, P1 ÷ T1 = P2 ÷ T2 (3.8 ≈ 3.7). Therefore, the system is not leaking. In the above formula, note that 3.8–3.7 = 0.1. **Anything over 0.2 warrants further checking.**

For wider temperature swings, the table below will be useful. Typical "normal" temperature-pressure relationships are as follows. **Deviations from these values warrant investigation:**

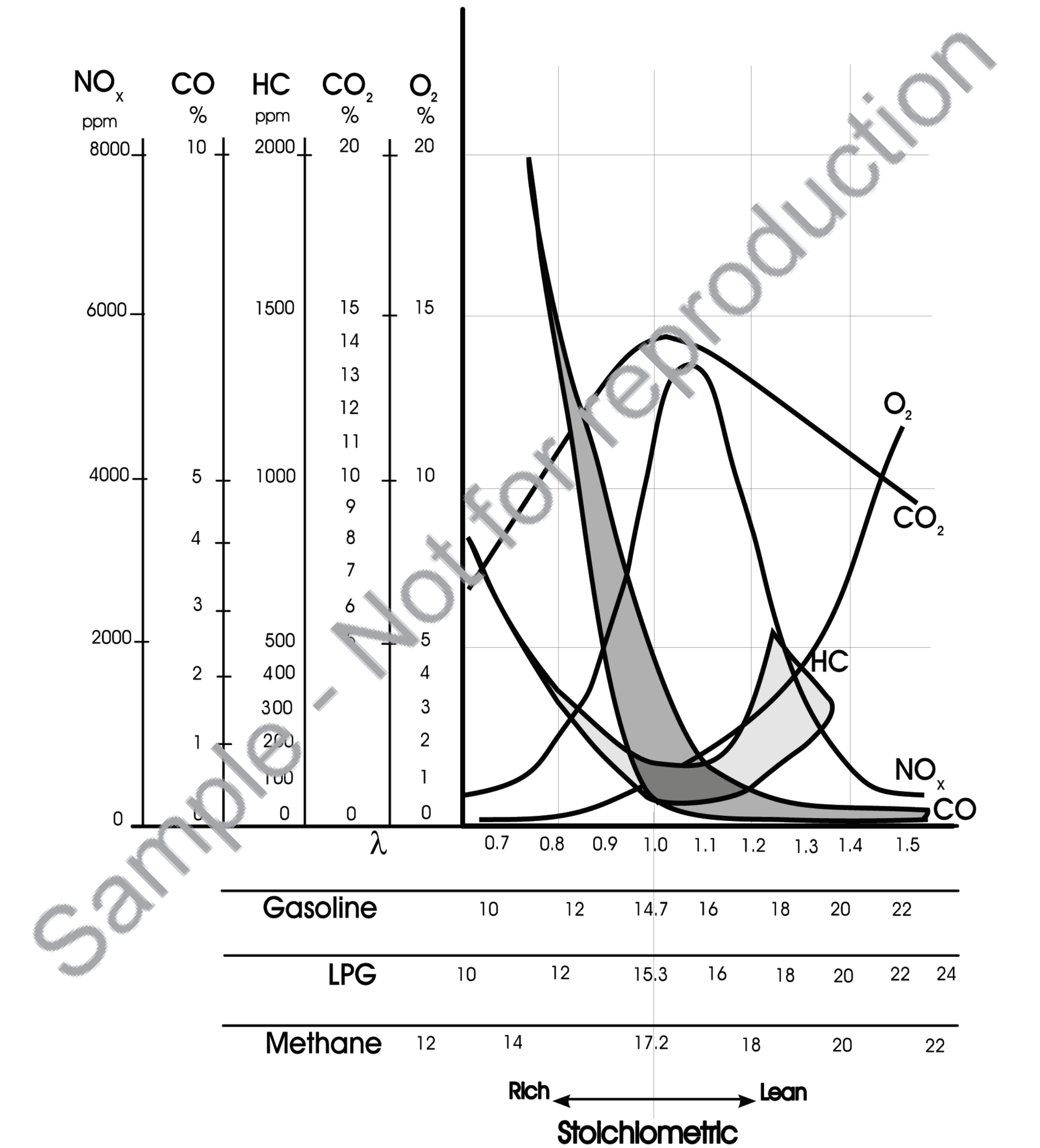
100.00°F	3,388.0 psig
90.00°F	3,257.7 psig
80.00°F	3,128.3 psig
70.00°F	3,000.1 psig
60.00°F	2,870.7 psig
50.00°F	2,740.2 psig
40.00°F	2,609.0 psig
30.00°F	2,477.2 psig
20.00°F	2,344.9 psig
10.00°F	2,212.1 psig
0.00°F	2,212.1 psig
-10.00°F	2,978.8 psig
-20.00°F	1,946.5 psig
-30.00°F	1,686.8 psig
-40.00°F	1,556.5 psig

Some light-duty vehicles use pressure and temperature measurements to **calibrate dashboard fuel gauges** so that an accurate reading will be displayed on the dashboard gauge or fuel meter, regardless of temperature. Using pressure only, the gauge will display readings equivalent to the temperature-pressure relationships above.

Notes.

CO_2 Balance Method

Typically, the air-fuel mixture is adjusted so that the percentage of CO is small (0.1 percent to 0.4 percent). This indicates that the engine is running close to stoichiometric, since low CO is a product of good combustion (see Figure 11-19).



Courtesy of West Virginia University

Figure 11-19: Relationship of AFR to emissions.