The Scientific and Political Challenges of Biofuels*

The most commonly produced biofuel is *bioethanol*, which is ethanol (C_2H_5OH) made from fermentation of plant carbohydrates. The fuel value of ethanol is about two-thirds that of gasoline and is therefore comparable to that of coal (Table 5.6). The United States and Brazil dominate bioethanol production, together supplying 85% of the world's total.

In the United States, nearly all the bioethanol currently produced is made from yellow feed corn. Glucose ($C_6H_{12}O_6$) in the corn is converted to ethanol and CO_2:

$$C_6H_{12}O_6(s) \longrightarrow 2\,C_2H_5OH(l) + 2\,CO_2(g) \qquad \Delta H = 15.8\text{ kJ}$$

Notice that this reaction is *anaerobic*—it does not involve $O_2(g)$—and that the enthalpy change is positive and much smaller in magnitude than for most combustion reactions. Other carbohydrates can be converted to ethanol in similar fashion.

Producing bioethanol from corn is controversial for two main reasons. First, growing and transporting corn are both energy-intensive processes, and growing it requires the use of fertilizers. It is estimated that the *energy return* on corn-based bioethanol is only 34%—that is, for each 1.00 J of energy expended to produce the corn, 1.34 J of energy is produced in the form of bioethanol. Second, the use of corn as a starting material for making bioethanol competes with its use as an important component of the food chain (the so-called food versus fuel debate).

▲ Figure 5.27 Sugarcane can be converted to a sustainable bioethanol product.

Much current research focuses on the formation of bioethanol from *cellulosic* plants, plants that contain the complex carbohydrate cellulose. Cellulose is not readily metabolized and so does not compete with the food supply. However, the chemistry for converting cellulose to ethanol is much more complex than that for converting corn. Cellulosic bioethanol could be produced from very fast-growing nonfood plants, such as prairie grasses and switchgrass, which readily renew themselves without the use of fertilizers.

The Brazilian bioethanol industry uses sugarcane as its feedstock (Figure 5.27). Sugarcane grows much faster than corn and without the need for fertilizers or tending. Because of these differences, the energy return for sugarcane is much higher than the energy return for corn. It is estimated that for each 1.0 J of energy expended in growing and processing sugarcane, 8.0 J of energy is produced as bioethanol.

Other biofuels that are also becoming a major part of the world economy include *biodiesel*, a substitute for petroleum-derived diesel fuel. Biodiesel is typically produced from crops that have a high oil content, such as soybeans and canola. It can also be produced from animal fats and waste vegetable oil from the food and restaurant industry.

5.97 At the end of 2012, global population was about 7.0 billion people. What mass of glucose in kg would be needed to provide 1500 Cal/person/day of nourishment to the global population for one year? Assume that glucose is metabolized entirely to $CO_2(g)$ and $H_2O(l)$ according to the following thermochemical equation:

$$C_6H_{12}O_6(s) + 6\,O_2(g) \longrightarrow 6\,CO_2(g) + 6\,H_2O(l) \qquad \Delta H^\circ = -2803\text{ kJ}$$

5.111 From the following data for three prospective fuels, calculate which could provide the most energy per unit mass and per unit volume:

Fuel	Density at 101.3 kPa (g/cm^3)	Molar Enthalpy of Combustion (MJ/mol)
Octane, $C_8H_{18}(l)$	0.70 at 20 °C	−5.53
Liquid Butane, $C_4H_{10}(l)$	0.60 at −1 °C	−2.88
Liquid hydrogen, $H_2(l)$	0.07 at −253 °C	−0.29

5.98 The automobile fuel called E85 consists of 85% ethanol and 15% gasoline. E85 can be used in the so-called flex-fuel vehicles (FFVs), which can use gasoline, ethanol, or a mix as fuels. Assume that gasoline consists of a mixture of octanes (different isomers of C_8H_{18}), that the average heat of combustion of $C_8H_{18}(l)$ is 5400 kJ/mol, and that gasoline has an average density of 0.70 g/mL. The density of ethanol is 0.79 g/mL. (**a**) By using the information given as well as data in Appendix C, compare the energy produced by combustion of 1.0 L of gasoline and of 1.0 L of ethanol. (**b**) Assume that the density and heat of combustion of E85 can be obtained by using 85% of the values for ethanol and 15% of the values for gasoline. How much energy could be released by the combustion of 1.0 L of E85? (**c**) How many liters of E85 would be needed to provide the same energy as 40 L of gasoline? (**d**) If gasoline costs \$3.88 per gallon in the United States, what is the break-even price per gallon of E85 if the same amount of energy is to be delivered?

5.117 It is estimated that the net amount of carbon dioxide fixed by photosynthesis on the landmass of Earth is 5.5×10^{16} g/yr of CO_2. Assume that all this carbon is converted into glucose. (**a**) Calculate the energy stored by photosynthesis on land per year, in kJ. (**b**) Calculate the average rate of conversion of solar energy into plant energy in megawatts, MW ($1\text{W} = 1\text{J/s}$). A large nuclear power plant produces about 10^3 MW. The energy of how many such nuclear power plants is equivalent to the solar energy conversion?

SAMPLE INTEGRATIVE EXERCISE

Putting Concepts Together

Trinitroglycerin, $C_3H_5N_3O_9$ (usually referred to simply as nitroglycerin), has been widely used as an explosive. Alfred Nobel used it to make dynamite in 1866. Rather surprisingly, it also is used as a medication, to relieve angina (chest pains resulting from partially blocked arteries to the heart) by dilating the blood vessels. At 100 kPa pressure and 25 °C, the enthalpy of decomposition of trinitroglycerin to form nitrogen gas, carbon dioxide gas, liquid water, and oxygen gas is -1541.4 kJ/mol.

(a) Write a balanced chemical equation for the decomposition of trinitroglycerin.

(b) Calculate the standard heat of formation of trinitroglycerin.

(c) A standard dose of trinitroglycerin for relief of angina is 0.60 mg. If the sample is eventually oxidized in the body (not explosively, though!) to nitrogen gas, carbon dioxide gas, and liquid water, what number of calories is released?

(d) One common form of trinitroglycerin melts at about 3 °C. From this information and the formula for the substance, would you expect it to be a molecular or ionic compound? Explain.

(e) Describe the various conversions of forms of energy when trinitroglycerin is used as an explosive to break rockfaces in highway construction.