Synthesis of Biodiesel

Chem Connections:

The diesel engine was first designed by Rudolf Diesel in 1895. The original diesel engines had two key design features. First they used "heaver fuels," in other words, fuels with longer carbon chains. Typical gasoline engines use saturated hydrocarbons with 7-11 carbon atoms per chain (high octane fuel). Diesel engines use fuels with longer chains, often containing between 12-18 carbon atoms. Rudolf Diesel envisioned running his diesel engine with vegetable oil, which contains three chains that are 16-18 carbons long (See Figure 1: octane, soybean oil, and petroleum diesel, biodiesel). His design became a reality in 1900, when the first diesel engines where produced and used peanut oil as a fuel source.

The second distinguishing feature of a diesel engine is that the fuel ignites without using a spark system. Compression of air before injection of the fuel creates heat, which ignites the fuel in a diesel engine. This is a great application of the ideal gas law!

This simple design allows engines to operate with higher efficiency than traditional gasoline engines which rely on spark plugs to ignite the air/fuel mixture.

These two design features, multiple fuel sources and higher efficiencies, have stimulated the resurgent interest in diesel engines. Biodiesel can be used in engines designed to run on petroleum diesel, making biodiesel an attractive renewable fuel. Biodiesel can be produced from many vegetable oil sources, and can even be made from oil which has already been used for cooking. This means that the 1-3 billion gallons of frying oil used in the US every year could be used to power vehicles instead of ending up in land fills or sewers!

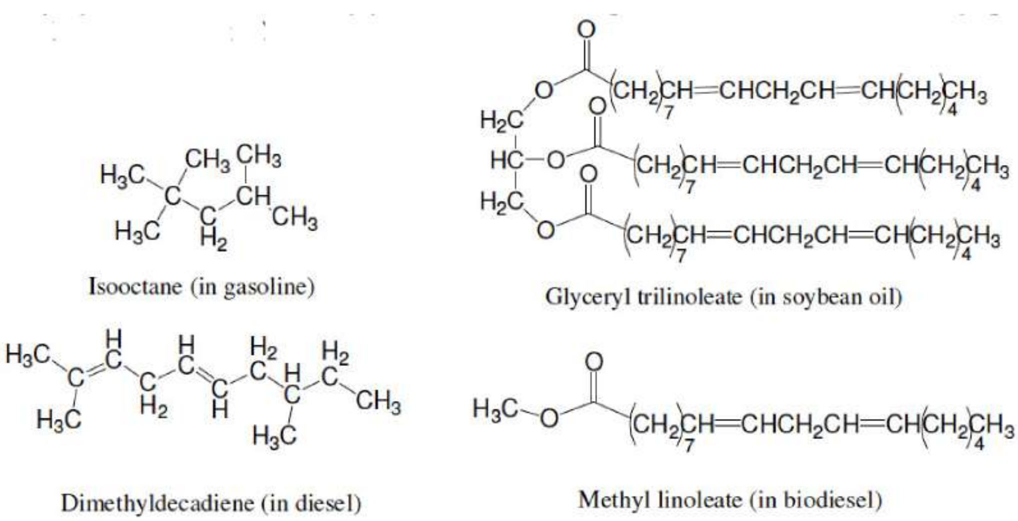

Figure 1: Primary Components in Common Fuels. The fuels currently used in combustion engines are all complex mixtures. The primary component of each fuel is shown above.

This experiment will give you the opportunity to make some biodiesel starting from vegetable oil. If you trust your chemistry skills you could even put your product from this lab into any diesel car. During this experiment you will get to see how this fuel burns.

Chemistry

In order to make biodiesel from naturally occurring oils the long chain hydrocarbons must be chemically separated. This can be accomplished through a process called hydrolysis. In your body this is the first step in the digestion of fats and oils in our diet.

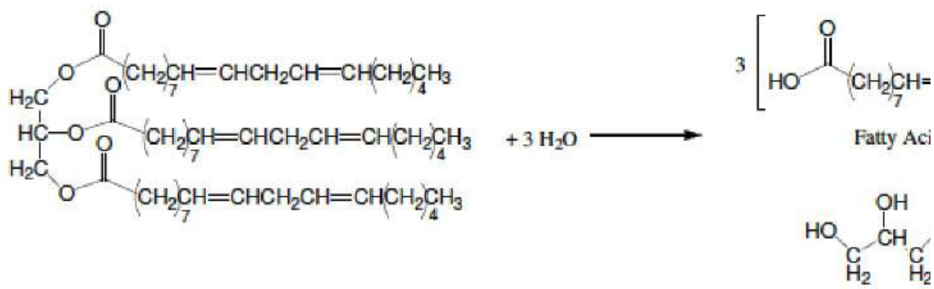

Figure 2: This process of breaking down oil into fatty acids and glycerol (also known as glycerin) proceeds very slowly without the addition of catalysts.

Notice that the reaction in figure 2 is balanced. By adding water the bonds between the fatty acid chains and the glycerol have been broken. This process proceeds very slowly without the addition of a catalyst. However, the hydrolysis reaction can be catalyzed by the addition of either an acid or a base (this is one of the reasons your stomach is an acidic environment). The product of the hydrolysis reaction is a carboxylic acid, attached to the long-chain hydrocarbon. Although this looks a lot like the biodiesel shown in figure 1, the carboxylic acid can be corrosive inside an engine. For this reason, chemists have devised another way to chemically modify the chains found in natural oils.

This new way is shown in Figure 3 below. Notice that instead of water, methanol is used along with NaOH, which is a strong base that will act to catalyze the reaction. No water is used and the desired product of the reaction belongs to a class of chemicals called esters. Esters are like carboxylic acids, but instead of having the form RCOOH, esters are terminated with a carbon chain RCOOR. Notice that esters were present in the original soybean oil. Since we changed one ester into another ester, this reaction is called a transesterification. What physical properties would change when the soybean oil is changed to three separate esters?

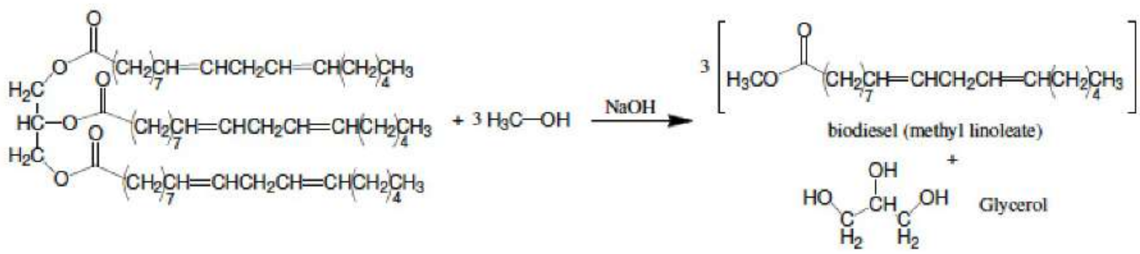

Figure 3: The process we will use to produce biodiesel from soybean oil.

In addition to the desired biodiesel, this reaction also creates the byproduct glycerol. Before the biodiesel can be used for combustion, the glycerol will have to be separated from the biodiesel. This is relatively easy because the two chemicals are immiscible (they do not mix) and they have significantly different densities. Biodiesel has a density of 0.884 g/mL and glycerol has a density of 1.261 g/mL. This means that the biodiesel will float on top of the glycerol.

Prelab Questions

1) Complete the table below for all of the reactants and products used in this experiment.

Chemical	mp (°C)	bp (°C) or smoke point	density (g/mL) at 25°C	Molecular Weight (g/mol)	Hazards
soybean oil	-21	241	0.894	879.4	
methanol					
sodium hydroxide					
methyl linoleate (biodiesel)	-35	373	0.884	294.5	
glycerol					
water					