Lesson Plan – Biofuels Production and Use

Goal

To understand the magnitude of transportation energy use, the process and implications of biofuel production, and the energy displacement potential of biofuels.

Key Concepts

1. Biofuels are fuels made from recently grown plant material.
2. Carbon in the biomass was recently captured from the atmosphere through photosynthesis.
3. Combustion of biofuels emits "biogenic" CO_2. Since this carbon is essentially recycled from the atmosphere, it is not considered to be as bad as the release of fossil carbon from the combustion of fossil fuels. That carbon had previously been sequestered underground.
4. Biofuels can often be made from "waste" materials. In particular, biodiesel can be made from waste vegetable oil (e.g., fryer fat)
5. A diesel engine is capable of running on raw vegetable oil, but it must be pre-heated to lower the viscosity. Biodiesel has a lower viscosity than pure vegetable oil.
6. If crops are grown for the purpose of creating biofuels, there may be significant environmental impacts associated with feedstock production.
7. Biofuel production requires feedstock production, feedstock processing, fuel production, and fuel use. It is important to consider environmental implications of all these "lifecycle" stages.
8. The increased use of biofuels is currently mandated by the U.S. federal government under the Energy Independence and Security Act of 2007. The goal is to produce and consume 36 billion gallons of biofuels per year by 2022. That includes 15 BGY of corn ethanol by 2015.
9. Currently, large-scale biofuel production relies on large-scale agricultural production of feedstock biomass. The feedstock production phase, especially in the case of corn ethanol relies on significant fossil fuel use and contributes to various environmental impacts.
10. The production of 5-6 billion gallons of ethanol in 2007 displaced only a small percentage (~2%) of our transportation energy use. An increase to 15 BGY by 2015 will put a significant burden on agriculture, food prices, ad fossil fuel use, while still displacing only a small fraction of our transportation energy.
11. Fuels have different heating (calorific) values and different viscosities. These differences affect engine performance

Background

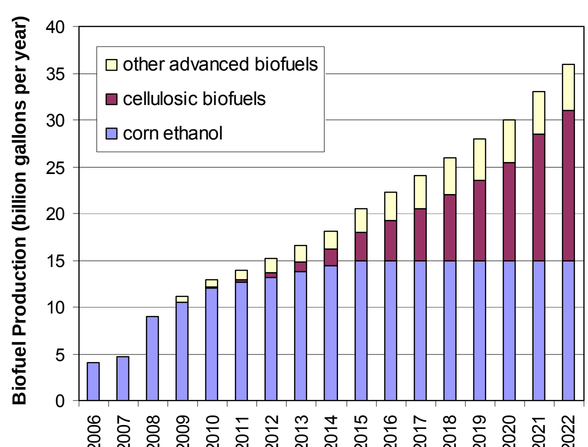
Biofuels are fuels made from recently grown plant or animal matter. Fossil fuels were also originally plant or animal matter, but that material has spent millions of years underground in extreme conditions and so it has changed significantly and its energy value was concentrated. As fossil fuel supplies diminish, renewable energy resources that can be replenished faster than we use them must be found in order for society to continue functioning as we are accustomed. Some folks believe that biofuels, like corn ethanol and biodiesel, could supply this renewable supply of fuel.

There are other negative environmental impacts related to fossil fuel use, in addition to the depletion of a limited resource. Many toxic chemicals contained in fossil fuels are released into the atmosphere upon burning of oil and coal. Biofuels are less toxic than fossil fuels - biodiesel is less toxic than table salt, for example. In addition, carbon released from the sequestered underground reservoirs of fossil fuels goes into the atmosphere as carbon dioxide. Most scientists agree that the human-caused increase in atmospheric carbon dioxide and other greenhouse gases are at least partially influencing global temperature. Thus, fossil fuel use influences global climate destabilization.

Biofuels are touted as a potential solution (at least partially) to the problem of greenhouse gases from fossil fuels. The biofuels still release carbon dioxide into the atmosphere, but since the fuel comes from recently grown plants, it was extracted from the atmosphere through photosynthesis, and will be reused by future crops. By limiting the amount of carbon moving from the underground to the atmosphere, the idea is to reduce the intensity of global warming.

Ethanol and biodiesel are now commonly mixed with petroleum-based fuels for sale as transportation fuels. Ethanol from corn is the most commonly used biofuel made in the U.S. In 2008, over 9 billion gallons of corn ethanol were produced. New technologies are available to make ethanol from cellulosic materials, including wood chips, switch grass, and corn stover, which is the stalk and leaf residue remaining after the corn grain is harvested. Biodiesel is made from soy beans or canola seeds, both of which have high oil contents. Approximately 0.7 BGY of biodiesel was produced in 2008.

U.S. legislation has shaped much of the national history of ethanol production. Bioethanol was first seriously considered as a transportation fuel in the 1970s due to the Arab Oil embargo. In 1990, a \$0.54/gal subsidy for the sale of gasoline blends that contain at least 10% ethanol (E10) helped to increase the number of ethanol production facilities. The U.S. Energy Independence and Security Act (EISA) of 2007 mandates that fuel producers use at least 36 billion gallons of biofuel by 2022. This includes 15 BGY of corn ethanol by 2015 and 21 BGY must be cellulosic biofuels. The legislation also



calls for a 20% reduction in oil use by 2010 through improved vehicle fuel economy and a national fuel economy standard of 35 miles per gallon by 2020. The 2022 EISA requirements would replace 15 % of the 2006 U.S. gasoline consumption on an energy basis.

Ethanol

Ethanol is made by the biological fermenting of sugars in the feedstock. If the feedstock does not contain sugars initially, pretreatment steps must precede the fermentation to transform the complex starches (corn) or cellulose into simpler sugar molecules. After the fermentation step, distillation is required to separate the ethanol from water.

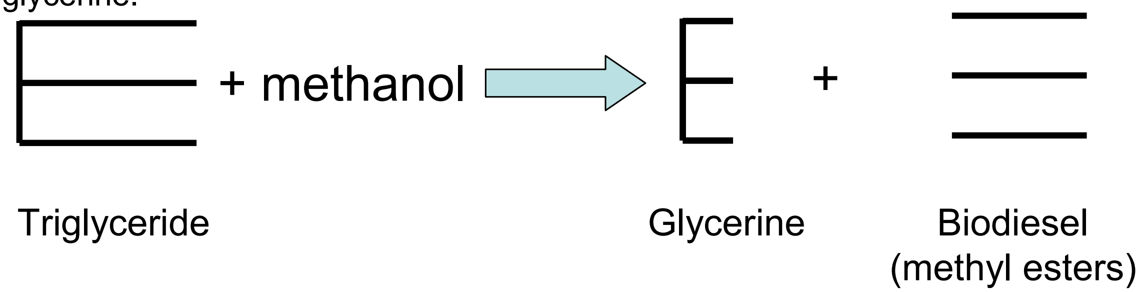
In the United States, the main feedstock for the production of ethanol is currently corn. **Approximately 2.8 gallons of ethanol (10 liters) are produced from one bushel of corn (35 liters)**. While much of the corn turns into ethanol, some of the corn also yields by-products such as DDGS (distillers dried grains with solubles) that can be used to fulfill a portion of the diet of livestock. A bushel of corn produces about 18 pounds of DDGS. Both the corn farming and ethanol production steps are very energy intensive. Diesel fuel and a lot of nitrogen fertilizer are used on the farm. Making the fertilizer requires a lot of energy and natural gas. The ethanol production step requires a lot of heat to keep the fermentation tanks warm and to distill the ethanol. On-site steam production from coal is often used in large-scale ethanol production facilities. Overall, even though the carbon in the fuel is “free” through the photosynthesis reaction, a lot of fossil fuels were also consumed to prepare ethanol for use as a transportation fuel.

Biodiesel

The diesel engine was originally designed to run on peanut oil. Modern diesel engines are designed to run on petroleum (fossil fuel) diesel, but can still run on vegetable oil if the oil’s viscosity is low. Warming the oil is required to lower the viscosity, so some alterations must be made to the fuel supply to the engine. The main reason for the use of petroleum diesel is its low cost and slightly higher energy value. Some people are promoting a return to vegetable oil for reasons of renewability and low pollution. By converting the oil to biodiesel, the energy value is increased and viscosity is lowered. This fuel can then be mixed with petroleum diesel (up to 20% mix (B20) can be used safely in any diesel engine) or can be used pure in many vehicles.

Biodiesel can be manufactured safely at a local community scale, while petroleum diesel requires a large refining infrastructure for safety and economy. In terms of energy independence and security for individuals, communities, states and countries, fuels such as biodiesel show promise when compared with the large scale operations of fossil fuel suppliers.

Biodiesel is created by reacting “natural” oils, or triglycerides, with an alcohol (usually methanol) in the presence of a catalyst. There are different methods for carrying out the reaction, but one of the simplest and most common is a base-catalyzed batch reaction of oil with methanol. This reaction is called transesterification. Any type of triglyceride, which includes plant or animal based oils, can be used as the feedstock. The base catalyst, typically lye (sodium hydroxide or potassium hydroxide), is mixed with the alcohol before the reaction is started. The alcohol/catalyst mixture is then added to the oil and the whole mixture is stirred vigorously. The overall reaction can be thought of as a big “E” in which the three fingers are cut off. The “fingers” and the molecules that comprise biodiesel, and the truncated remaining “E” is the glycerine.



Simplified conceptualization of transesterification reaction

$$\begin{array}{l} CH_2-O-C(=O)-R \\ \vert \\ CH_2-O-C(=O)-R \\ \vert \\ CH_2-O-C(=O)-R \end{array} + 3\,CH_3OH \rightarrow 3\,CH_2-O-C(=O)-R + \begin{array}{l} CH_2-OH \\ \vert \\ CH-OH \\ \vert \\ CH_2-OH \end{array}$$

Triglyceride (vegetable oil) | Methanol+Catalyst | Methyl Esters (biodiesel) | Glycerin

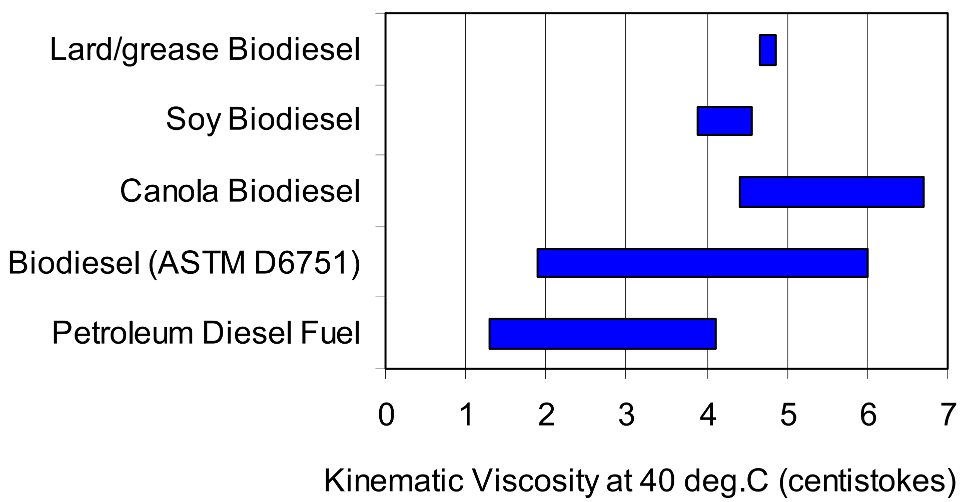
Transesterification of Triglyceride with Alcohol

After the reaction occurs, there will be two products, which separate into phases (like oil and water). The lower density phase (on top) is the biodiesel, and the higher density phase is glycerin. Glycerin can be used in other processes such as making soap or dynamite. In a high-end biodiesel production facility, the biodiesel must be cleaned before it can be sold as fuel.

Properties of Biofuels

The heating (calorific) value is an important physical property of all fuels. The calorific value of diesel is 46 MJ/Kg, kerosene is 47 MJ/Kg, biodiesel is 33–40 MJ/Kg, and canola oil is 36.9 MJ/Kg.[i] In the experiment performed during this lesson, students will use a simple calorimeter to calculate the calorific values of these four fuels.

The viscosity of a fluid can be expressed as a "dynamic viscosity" and a "kinematic viscosity". Dynamic viscosity is measured in "centipoise" while kinematic viscosity takes into account the fluid density and is measured in "centistokes". It is important to note the temperature of the measurements because the viscosity of a liquid will be reduced as the temperature rises. For example, the range of viscosity seen for canolabiodiesel is 4.43 to 6.7 centistokes at 40°C; this drops to around 2.4 centistokes at 100°C.



The maximum viscosity is limited by the design of engine fuel injection systems. The maximum allowable viscosity for No. 2 diesel is 4.1 centistokes at 40°C although most engines are designed to operate on fuels of higher viscosity. ASTM D6751 allows for slightly higher viscosity for biodiesel. Mixing biodiesel with petroleum diesel lowers the overall viscosity.

B100 freezes at higher temperatures than most conventional diesel fuel and this must be taken into account if handling or using B100. Most B100 starts to cloud at between 35°F and 60°F, so heated fuel lines and tanks may be needed even in moderate climates. As B100 begins to gel, the viscosity also begins to rise, and it rises to levels much higher than most diesel fuel, which can cause increased stress on fuel pumps and fuel injection systems. Cold weather properties are the biggest reason many people use biodiesel blends.

Key Terms

- **Biofuel –** fuel made from recently grown plant or animal matter.
- **Biodiesel** – a type of fuel made by a transesterifcation reaction from natural oils that can be used in a diesel engine with minimal or no alterations.

- **Viscosity** – the property of a fluid that resists the force tending to cause the fluid to flow.
- **Glycerin** – a co-product of biodiesel manufacture.
- **Heating value** – the heat energy released through the exothermic oxidation (combustion) reaction when a fuel is combusted.

Student Learning Objectives	NYS Standards[ii]
Learn to ask "why" questions to seek greater understanding concerning objects and events they have observed and heard about	Science Standard 1.
Energy exists in many forms, and when these forms change energy is conserved.	Science Standard 4.
(more needed)	

Lesson Plan

This is a multi-day lesson that includes an introduction to biofuels, how they are made and their pros and cons.

Introduction to Biofuels (1-2 days)

1. Review general concept – why we need alternative fuels
    a. Depletion of fossil fuels (which have been great for past century – cheap, abundant fuel supply, but that won't last forever)
    b. Climate change – combustion of fossil fuels for transportation are a major source of greenhouse gases
    c. Other toxic air pollutants
    d. Energy independence – need less dependence on foreign oil
    e. Review project – what we will be doing, how biofuels fit
2. Brainstorm – What do we already know about biofuels? (on board - build table of information about biofuels as the discussion progresses)
    a. What are biofuels?
    b. What are some examples of biofuels? What are they made of
        i. Show samples (in sealed glass vials)– see if students can guess what the fuels are (gasoline, diesel, ethanol, biodiesel from pure vegetable oil, biodiesel from fryer fat). Observe similarities and differences (viscosity, color)

Fuel Type	**Feedstocks**	**Process**	**Use**
Ethanol	Corn, sugar cane, corn stover, switchgrass	Fermentation, cellulosic technology	Replacement for gasoline
Biogas	Manure, compostable waste	Bacterial degradation	Replaces natural gas – cooking, heating, electricity
Green Diesel	Gas or low MW hydrocarbons	Fischer-Tropsch chemical reaction, Pyrolysis	Replacement for diesel
Biodiesel	Any naturally occurring oils, fresh or recycled	Base-catalyzed transesterification	Replacement for diesel
Biobutanol		fermentation	Replacement for gasoline

c. Other issues/questions

   i. Oil and coal came from biomass, are they biofuels too?

   ii. Where did the carbon come from that comprises biomass? Fossil fuels? Is this carbon the same in terms of climate change concerns?

d. Emphasize a generic approach to understanding biofuels – build generic process flow diagram, starting with the "use" of fuel.

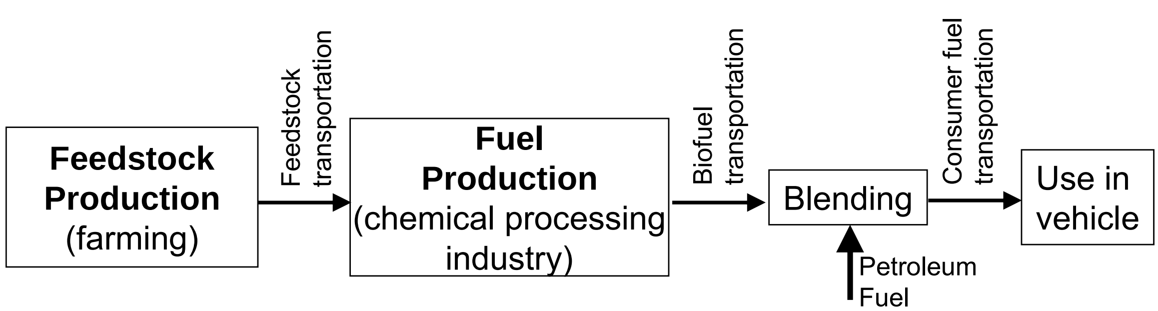
   i. What kind of transportation vehicles can run on biofuels?

   ii. How are they made (in general) and used? (draw general process flow diagram)

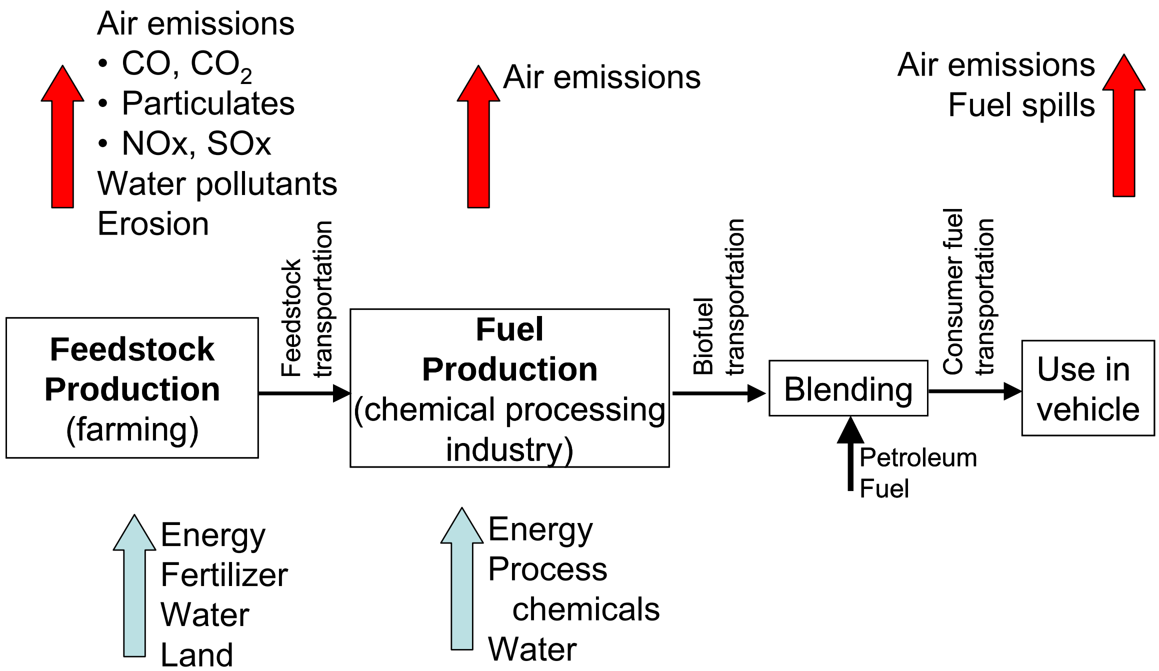
      1. Fuel must be made from a feedstock that is grown, harvested and transported (the "grown" aspect of this not applicable to waste oil which must be collected and transported only)

      2. The feedstock must be chemically or biologically converted into a fuel in a manufacturing industry.

   iii. What other inputs are required to make this process happen?



Initial generic process flow diagram



Process flow diagram with greater detail

e. What benefits and concerns have you heard about biofuels
   i. reduced GHG emissions
   ii. renewable fuel
   iii. food vs. fuel concerns (price, availability (especially in poor countries))
   iv. Land and water use

3. How much biofuels are required?
   a. Identify EISA goals for biofuel production
      i. 15 BGY bioethanol by 2015
      ii. 36 BGY total biofuels by 2022
   b. Use visual aids to help students understand the quantities involved
      i. Show 2 ¾ gallons of "ethanol" (jugs of water) = ethanol from 1 bushel of corn
      ii. Show 1 bushel basket
      iii. 145 bushels of corn come from an acre
      iv. 1 acre is about the size of a football field or 43,000 square feet
      v. Do math – (emphasize units)
         1. ethanol from one football field

$$2.75\frac{gal.\,etoh}{bu\ corn} \times 145\frac{bu\ corn}{acre} \times 1\frac{acre}{football\ \ field} = \sim 400\frac{gal.\,etoh}{football\ \ field}$$

2. number of football fields to generate 15 BGY corn ethanol

$$\frac{15{,}000{,}000{,}000\,\frac{gal.\,etoh}{y}}{400\,\frac{gal.\,etoh}{football\ \ field}} = \sim 38\ million\ \ football\ \ fields$$

c. Can compare this to how many classrooms of water that would take to make ethanol

   i. Pull aside one of the gallons of fake “ethanol” then bring out four more gallons of water to show that each gallon of ethanol requires four gallons of water to make.

   ii. That is only in the fermentation stage - hundreds of gallons of water are required (exact number depends on geography) to grow the corn for a gallon of ethanol.

d. Define energy density:

   i. the amount of energy or heating value contained in a volume of fuel.
   ii. Remember hydrogen has a very low energy density by volume, but high energy density by mass.
   iii. Ethanol is less energy dense than gasoline, by volume
   iv. So if your car could run on pure ethanol, you could fill up your tank with it, but you would not get as far as you would on a tank of gas
   v. It takes about a gallon and a half of ethanol to get the same energy as one gallon of gasoline.

4. Optional - Hand out ethanol calculation homework to continue with these types of calculations
   a. Project Ethanol worksheet and explain
   b. Go through data section on left, explain units and magnitudes
   c. Quickly go through questions on right, demonstrate calculations on first question or two
   d. If time allows, have students go to computer lab to go through all questions on their own and calculate results
   e. If not enough time, go through the worksheet as a class or send home as homework.
   f. Discussion questions on EtOH worksheet
      i. What percentage of our transportation energy use would the proposed 15 BGY ethanol displace?
      ii. Is that displacement significant? Do you think it is worth it?
      iii. Is it important to consider water use in producing biofuels? How about land area? Why?

5. Wrap up
    a. Limits to continued use of fossil fuels for transportation
    b. Biofuels mandated by Congress, will contribute to our future transportation fuels
    c. There are both benefits and concerns about the extended use of biofuels
        i. What is it about biofuels that makes them so popular?
        ii. Feedstock production has to be considered for expanding biofuel use.
        iii. More detail on this topic when we cover life-cycles of fuels.

Next time: Make biodiesel

Biodiesel Production and Testing (2 days)

1. Explain that we will be learning about and making biodiesel, how it is useful in relation to regular diesel.
    a. Diesel engine was originally designed to run on peanut oil
    b. Petroleum diesel has a slightly higher energy value and is cheaper than plant oils, but more polluting
    c. Could still run diesel engine on vegetable oil, but there are problems with viscosity so special heaters need to be installed
    d. Any type of naturally occurring oil can be used to make biodiesel
    e. Biodiesel has energy more readily available than vegetable oil, and a lower viscosity so it is much easier to use in a diesel engine.
    f. Up to 20% biodiesel in petroleum diesel can be used safely in any diesel engine

2. Background about requirements for biodiesel
    i. Process – explain in simple terms
        i. Oil is mixed with methanol (alcohol) and catalyst (lye-sodium hydroxide)
        ii. Must be mixed because there are **two liquid phases**
        iii. Heated to speed up reaction
        iv. Settling, separation, washing
    ii. Feedstocks
        i. Options
            a. fresh veg oil - soy, Jatropha, rapeseed
            b. used veg oil - fryer oil

c. Animal fats - bacon grease, alligator fats, processing ‘byproducts’

ii. Consider implications of feedstock requirements

a. If specific crops are grown for making biodiesel, other emissions occur upstream, parallel to the H2 car scenario

b. Can waste oil supply feedstocks? - parallel to using renewable energy for H2 production

c. Making biodiesel activity

i. Feedstocks: Fresh soybean oil; Used vegetable oil; Bacon Grease?

ii. Recipe

a. 250 mL Oil

b. Put in 500mL flask on heater/stir plate

c. Heat to 55 °C

d. Add Methoxide – turn heat down or off (Previously prepared 50 mL Methanol mixed with 0.875 g NaOH)

e. Stir vigorously for up to 30 min

f. product will have to stay overnight to settle

d. Discuss chemistry of biodiesel (done while reaction running)

i. triglyceride molecular structure (**get to know this well, so you can explain easily)**

ii. transesterification

iii. ratios of reactants (hint at this, its a discussion question)

a. Molar 1 oil:3 MeOH

b. Volume/mass ~5 oil:1 MeOH

iv. emulsions (also hint at this, another discussion question) –

a. reaction surface

b. stability/separation

e. Wrap up

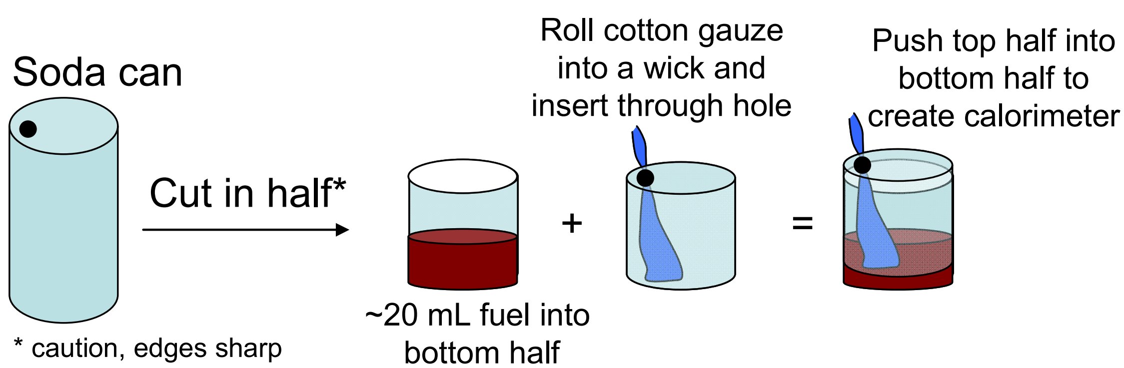
i. Making biodiesel – simple, can be done at home –

a. can do at small scale (directions for making biodiesel: http://journeytoforever.org/biodiesel_make.html

b. Local production more secure/sustainable

ii. Next time – Calorimeter lab, energy of fuels

3. Testing Biodiesel (day 2 of biodiesel activities)
    a. Introduce the concept of the heating value of a fuel (see text in activity sheet). Specifically point out
        i. that the exothermic chemical reaction required to create heat energy that is converted in an internal combustion (or diesel) engine) to mechanical energy to move a vehicle.
        ii. That the heating value of petroleum fuels is very high, that helps to make them a very valuable resource. The heating value of biofuels is less than their petroleum counterparts.
    b. Introduce the concept of the lab experiment.
        i. Use a candle to show that the mass of the fuel is lost as combustion proceeds, we can use that mass loss and some measure of heat released to quantify the heat value of a fuel.
        ii. In a calorimeter, the heat released from fuel combustion is used to heat water. We can estimate the change in the heat energy in the water from the change in the temperature and the specific heat of water.
        iii. It is assumed that heat released from combustion = heat gained by water. However, the calorimeter is not 100% efficient. This introduces experimental errors.
        iv. Review the equations and measurements required
        v. Model the assembly of the calorimeter
    c. The lab should take most of the period.



    d. While the fuels are combusting, show students demo of “fuels on ice” to illustrate some of the down sides of biodiesel
        i. Set up water and ice baths at different temperatures.
        ii. Submerge into the water/ice baths vials of diesel fuel, soy oil and biodiesel that the students made.
        iii. Observe the vials for cloudiness and viscosity, discuss implications.

e. Wrap up – reaffirm the overall concept, discuss experimental errors, make sue the students understand lab report assignment.

Assessment

- Ethanol calculation homework (optional)
- Biodiesel production activity sheet
- Calorimeter laboratory report

Resource Files

- Ethanol Calculation homework
- Activity – Making Biodiesel
- Activity – Calorimeter

[i] "Calorific values of solid, liquid and gaseous fuels." http://www.kayelaby.npl.co.uk/chemistry/3_11/3_11_4.html. Website accessed 28 Nov. 2007.

[ii] University of the State of New York State Education Department (NYSED). http://www.emsc.nysed.gov/ciai/mst.html. Website accessed 28 Nov. 2007

Activity – Making Biodiesel

Purpose

In this activity we will be making biodiesel, a fuel that functions in diesel engine with little or no alterations. The main advantages of biodiesel are that it is easy and relatively safe to make, has a low toxicity and high biodegradability, and is near "carbon neutral".

Supplies

Safety glasses
Gloves
Heating stir plate with stir-bar
500 mL erlenmeyer flask
250 mL of oil (feedstock)
50 mL of Methoxide (methanol with catalytic amount of NaOH - 0.875g)
Thermometer

Safety Considerations

Methanol and sodium hydroxide are dangerous substances and should be handled with caution! Methanol is poisonous to skin and by ingestion, and its fumes are highly flammable. NaOH is a strong skin irritant and can cause blindness! Always wear gloves and goggles when working with these chemicals, and keep any sparks or flames away from methanol containers

Instructions

1. Put on safety glasses. Be aware that methoxide is flammable, poisonous, and caustic; and that we will be working with heat.
2. Put the stir bar into your 500mL flask, place the flask on the heated stir plate and turn the heat onto high. This will be your reaction vessel.
3. Pour your oil sample into the reaction vessel. Make and record observations of the raw oil feedstock (color, viscosity, clarity, etc.)
4. In order for the reaction to proceed at a reasonable pace, the oil must be warmed before adding the methoxide. Make sure the heat is on under your reaction vessel, and turn on the stirrer to speed up the heating process. Use your thermometer to keep track of the oil temperature.
5. When the temperature reaches 55 degrees C, the oil is ready.
6. Turn off the heat plate, the residual heat in the oil will be enough to help the reaction along.
7. Turn off the stirrer.
8. **Carefully,** and slowly ad the 50mL of methoxide to the reaction vessel.
9. Make and record observations about the mixture. Are the reactants **homogeneous**, or are their layers? If there are layers, which reactant is on top and which is on the bottom?

10. Now turn up the stirrer to full power. Mixing speeds up the reaction by emulsifying the two phases and allowing the reactants to come together more easily.
11. Continue stirring and allow the reaction to proceed for up to 30 minutes. After this time, most of the reactants have been used up, so the remaining reaction is insignificant.
12. Allow the flask to cool, or use a hot glove to grasp it, and pour the contents into an appropriate container, provided by the teacher, to allow for settling. The biodiesel will separate from its byproduct over the course of about 24 hours.
13. The following day – observe layers, decant biodiesel.

Observations

Raw oil feedstock:

Initial mixture of reactants:

During reaction:

After reaction, before settling:

After reaction, after settling:

Discussion Questions

1. What are the reactants used to make biodiesel in this lab? What are some options for reactants, or “feedstocks”, that could be used to make biodiesel?

2. Based on the balanced chemical equation for the biodiesel formation reaction, what ratio of the two reactants is required to allow the reaction to proceed to completion?

3. What was the ratio of the volumes of the reactants used in this lab? Does this volumetric ratio match the ratio of the reactants in your answer to Question 2? Why or why not?

4. The biodiesel reaction occurs between two liquid phases, an aqueous (hydrophilic) phase and a lipophilic (hydrophobic) phase – the reactants do not readily mix together, nor do the products. Discuss one advantage and one disadvantage resulting from the nature of this two-phase liquid reaction that would have to be considered in designing a process for biodiesel production.

Activity – Calorimeter Experiment

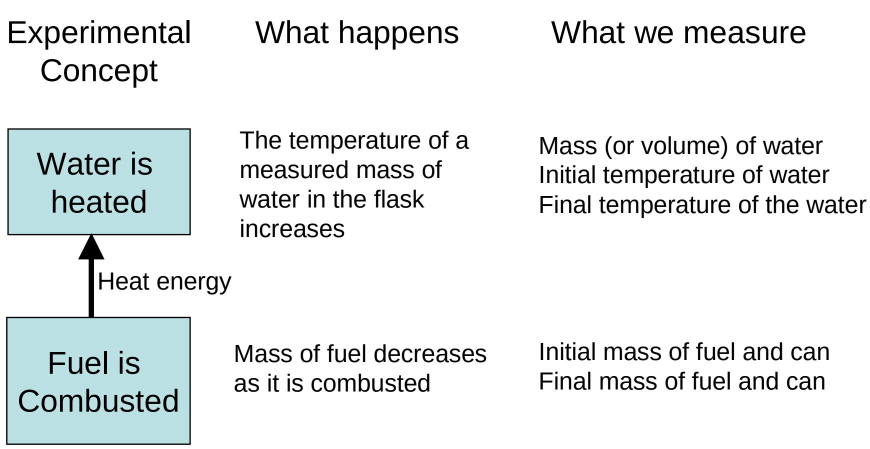
Overview

Fuels that we use have a wide variety of Heating Values. The heating value defines how much heat is generated in the exothermic combustion reaction when the fuel is burned. The heating value can be presented in terms energy released per the number of the moles, or mass or volume of fuel. Petroleum fuels have very high heating values, this makes them a very desirable fuel. Biofuels generally have a lower heating value. Thus, you often need to use more volume of biofuels than volume of a comparable petroleum fuel.

Gasoline	125,000 Btu/gal	Ethanol	76,000 Btu/gal
Diesel fuel	128,450 Btu/gal	Biodiesel – Waste vegetable oil	120,000 Btu/gal

A calorimeter is a tool used to measure the heating value of a fuel. This name came from the standard use of "calories" as a measure of heat energy. A calorie is the amount of heat required to heat one gram of water one degree Celsius. Heat energy is also often measured in Joules (J) and British Thermal Units (Btus).

In a calorimeter, the fuel is burned creating a source of heat, which is used to heat water. The increase in the water temperature is directly proportional to the heat input to the water. The figure below illustrates the basic concept.



The heat that is used to raise the temperature of the water can be calculated based on the specific heat of water:

$$Q = m*c*\Delta T$$

Where:

Q is the heat flow (calories)
m is the mass of the water (grams)
c is the specific heat of water (c = 1 calorie/gram)
ΔT is the temperature change (°C)

It is assumed that the heat energy used to raise the water temperature equals the heat released by the exothermic combustion reaction.

The quality of the measurements depends on the efficiency of the system in directing all heat from the flame to the water. Any losses to the ambient air and water/fuel containers will reduce the calculated heat value of the fuel.

Purpose
The purpose of this experiment is to measure the heating value of a fuel (MJ/kg). The biodiesel generated in the previous class will be tested alongside other standard fuels.

Safety Aspects

- The combustion of fuels is inherently dangerous. The experiment requires open flames. Safety goggles must be worn and no loose hair or clothing allowed.
- The fuel and water vessels get very hot; tongs of insulated gloves are required for disassembly and the final weighing of the fuel.
- Some fuels create a lot of smoke when combusted. A fume hood or room with great air ventilation should be used.

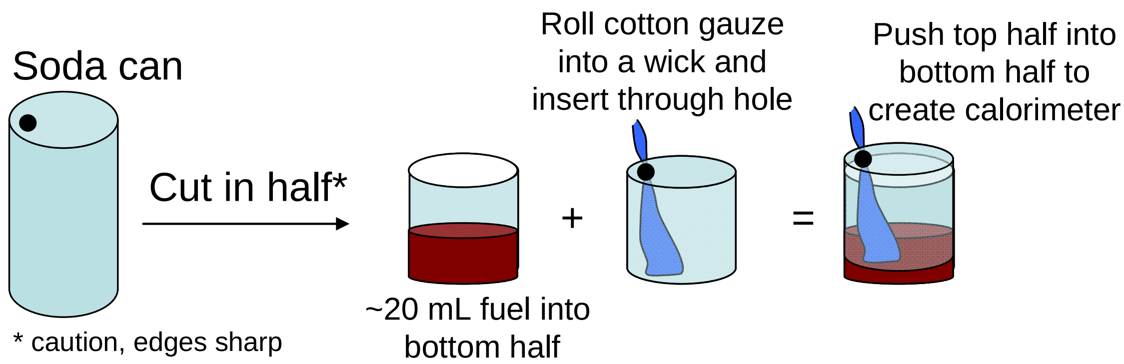
Materials

- Erlenmeyer Flask
- Ring Stand
- Graduated Cylinder
- Thermometer
- Soda can calorimeter (see notes below)
- Wick made of Cotton Gauze or cheesecloth (2 × 10 cm)
- Aluminum Foil Shields
- Water (200 mL)
- Fuel (~20 mL) (one type per group: biodiesel, canola or soy oil, petroleum diesel)
- Safety glasses
- Tongs or gloves to hold hot objects

Instructions

- Put your safety goggles on and tie back any long hair.
- Record your fuel type in the Data Table.
- Assemble the calorimeter (see the figure below).
    - Use approximately 20mL of your fuel into the bottom half of the soda can calorimeter. It should be about ½ to 1 inch deep.
    - Roll the cotton gauze wick and insert through drinking hole in can top. Drip a few drops of fuel onto the top of the wick to make sure there is fuel to burn at the top
    - Assemble the calorimeter carefully (edges are sharp)

- o Weigh the entire apparatus and record weight in the data table.



- Assemble the water heating flask:
  - o Pour 200 mL of water into the flask (using the graduated cylinder).
  - o Place the flask on the ring stand (or use a clamp as your teacher directs); approximately ten centimeters (~ 4 in.) above the base.
  - o Measure the temperature of the water in your can and record the initial temperature.
- Place the soda can fuel container below the flask of water.
- Place your aluminum foil shield around the bottom of the flask like a skirt.
- Carefully light the wick and let the fuel burn for about ten minutes, or until you get about 30-40°C change in temperature. The time required will vary with different fuels. Use a thermometer in the flask to slowly stir the water.
- Extinguish the wick by covering with ceramic crucible.
- Record the final temperature of the water. Remove the aluminum foil skirt, and record the final mass of the soda can (with remaining fuel and wick).

Data Table

FUEL TYPE:		
Mass of soda can and fuel before burning:	______	grams
Mass of soda can and fuel after burning:	______	grams
Volume of water in flask:	______	mL
Initial water temperature:	______	°C
Final water temperature:	______	°C

Calorimeter Experiment - Calculations

1. Calculate the mass of fuel combusted (grams).

2. Calculate the change in temperature of the water due to heating by the fuel (°C).

3. The density of water is 1g/mL. Calculate the mass of water you heated (grams).

4. Calculate the heat flow in calories released by combusting your fuel, use the following formula and check your units:

   $Q = m*c*\Delta T$

   Where:

   Q is the heat flow (calories)
   m is the mass of the water (grams)
   c is the specific heat of water (c = 1 calorie/gram)
   ΔT is the temperature change (°C)

5. The metric unit of energy is the joule (J). Calculate the number of joules released during your fuel combustion. (1 calorie = 4.186 joules)

6. Divide the number of joules released by the mass of oil combusted. What is the heating value of your fuel (MJ/kg)?

Calorimeter Activity – Lab Report Instructions

For this lab you will be required to write a lab report. The lab report must include the following sections.

1. **Introduction –** Give some background about the different fuels we combusted, and why we might be interested in measuring their heating values. **[1/2 – 1 page]**

2. **Objective –** One sentence describing the goal of the lab.

3. **Procedure –** Basically repeat the procedure described in the lab in paragraph form. But leave out obvious stuff (like "pour water into flask") and expand a little on *why* the main steps (like "record the starting mass of your fuel") are important. **[1/2 – 1 page]**

4. **Results –** Restate the results you recorded in the data table, the calculations you did, and the results of the calculations. **[1 page]**

5. **Discussion –** Answer the discussion questions, and relate them to the experiment where appropriate. **[1 – 2 pages]**

6. **Conclusion –** Brief overview of the entire lab report, stating the main results, any problems you had, and suggestions for future labs. **[1 page]**

Discussion questions:

1. How do your results compare to the reported heating values of diesel (46 MJ/Kg), biodiesel (33–40 MJ/Kg), or canola oil (36.9 MJ/Kg)[1]?

2. How does the experiment we performed differ from an ideal, controlled experiment?

3. Where do you think the biggest errors came from?

4. Why is the heating value of biodiesel reported as a range?

5. Which fuel (diesel, biodiesel, or vegetable oil) is most "efficient" in a vehicle? Explain your answer?

6. Sample problem: The mass heat of combustion of Fuel B is 1,250 kJ/g. If you were to burn 15 grams of this compound in a bomb calorimeter (a special device that allows almost no heat loss) with a reservoir that holds 2.50 L of water, what would the expected temperature increase be?

[1] "Calorific values of solid, liquid and gaseous fuels." http://www.kayelaby.npl.co.uk/chemistry/3_11/3_11_4.html. Accessed 28 Nov. 2007.