Eve Perara, Ph.D.; Director of Diversity, Education, and Outreach
Nadine Gruhn, Ph.D.; Managing Director
Center for Enabling New Technologies Through Catalysis

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Small-scale biodiesel production as a classroom activity

The development of sustainable methods for creating transportation fuels is one of society's greatest challenges and a topic of great interest to the public at large. Biodiesel has received a lot of attention as a potential sustainable transportation fuel; it is used on a small scale in the US by fleet vehicles for small businesses and some government vehicle fleets including school and transit buses, military vehicles and more. Meyer and Morgenstern have developed a small scale biodiesel production laboratory exercise for environmental science and general chemistry students that involves taking vegetable oil to produce a biodiesel fuel, demonstrating intermolecular forces in a practical way.[1] This exercise demonstrates the importance of chemistry in addressing the problem of developing ecologically friendly and sustainable sources of fuel and provides a platform for discussion of the merits of different sources of renewable energy including biodiesel, solar and wind energies.

Below is a description of a modification of the published exercise that CENTC used in local high schools. Teams of graduate students and postdocs lead the exercise and included time for talking about chemistry as a career and how their own interests in chemistry developed.

Small Scale Biodiesel Production Exercise

Equipment and supplies:

1. Heated stir plate
2. Stir bar
3. 125 ml Erlenmeyer flask
4. 0.9 M NaOH/methanol solution to make $NaOCH_3$*
5. Vegetable oil
6. Waste containers
7. Thermometers
8. Tea candles – two per group
9. Multi-purpose lighters
10. Hexanes
11. Screw cap (e.g. scintillation) vials
12. Magnetic wand
13. Aluminum foil
14. Waste containers
15. Funnels
16. Absorbent underpads
17. Trays
18. Safety goggles
19. Nitrile gloves
20. Labeling tape
21. Waterproof markers
22. 100 ml graduated cylinders

[1] Meyer, S. A. and Morgenstern, M. A., *Small Scale Biodiesel Productions: A Laboratory Experience for General Chemistry and Environmental Science Students*, Chemical Educator, **2005**, 10, 1-3.

* For 10 groups, measure 150 ml of methanol into 500 ml Erlenmeyer flask (before handling methanol read safety data sheet (MSDS) https://www.labchem.com/tools/msds/msds/VT430.pdf). Weigh out 5 g sodium hydroxide (see MSDS www.labchem.com/tools/msds/msds/LC24350.pdf) Crush pellets into powder with mortar and pestle, transfer into methanol and stir on magnetic stir plate for 5-10 min. until dissolved.

Procedure:

Use safety goggles at every step of the procedure. Gloves are also useful when handling materials.

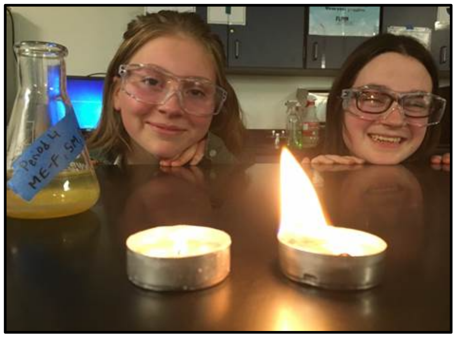
1. Pour 14 ml of 0.9 M NaOH/methanol solution into 125 ml Erlenmeyer flask. The sodium hydroxide reacts with the methanol to form sodium methoxide ($NaOCH_3$) by this reaction:

$$NaOH + CH_3OH \rightarrow NaOCH_3 + H_2O$$

2. Add 60 ml of vegetable oil to flask. Add stir bar and, using a heated stir plate on low setting, slowly heat the solution to a temperature between 35° C and 50° C with constant stirring, about 20 – 30 minutes. Check thermometer frequently taking care not to break it with the stir bar.

3. Let mixture cool and separate into two distinct layers. The clear, yellow top layer is the biodiesel product. The cloudy, colorless bottom layer contains glycerol, methanol and salts. The bottom layer may be a slightly solid plug. This is OK. Carefully pour the top layer into a graduated cylinder trying not to disturb the bottom layer. Record the volume of your biodiesel product and calculate the percent of biodiesel conversion based on the volume of oil you began with. The generally accepted conversion rate is about 70%.

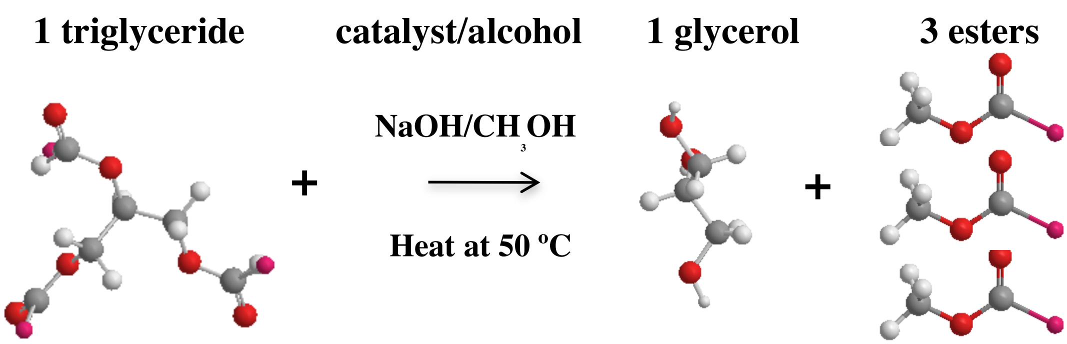
4. Remove candles from two tea candle tins and add a small amount of biodiesel into one and starting oil into the other. Swirl gently and notice any differences in viscosity. Replace wicks and fill the tins containing wicks – one with the starting oil and the other with the resulting biodiesel fuel. Use a lighter to light the wicks. Observe how each oil burns. The biodiesel should burn more vigorously than the starting oil. Pour glycerol and biodiesel into waste containers.



Teaching points

Catalysis – use of chemicals that accelerates rate of reaction while not being consumed in the reaction. In this case the catalyst is methoxide in the form of sodium methoxide. In larger scale biodiesel production, the catalyst can be separated from the products and reused in another reaction.

Glycerol waste - Referring to the chemical reaction, one can see that for every molecule of fuel generated, a molecule of glycerin is also generated. Glycerin is considered a co-product of biodiesel production and in order for biodiesel to be used on a wide scale, scientists must develop a way to use glycerin to manufacture products that are useful on a scale similar to biodiesel fuel. Glycerin can be used for making soap, but the demand for the soap is much lower than that for the fuel. Scientists are currently working on ways to use the glycerin for development of other useful chemicals.



Vegetable Oil

Intermolecular forces – Intermolecular forces explain the different viscosities of the starting vegetable oil, the biodiesel product and the glycerol. Biodiesel is less viscous than the starting oil because the smaller esters are more mobile than the larger triglycerides that comprise vegetable oil. Hydrogen bonding of glycerol molecules makes it very viscous. Glycerol and biodiesel end-products separate into two phases due to their different polarities. Biodiesel is a better fuel than vegetable oil because it is comprised of smaller molecules, thus has a lower melting point and is more volatile than vegetable oil, so it burns more readily.

Logistical issues of using biodiesel and comparison with other energy sources – The realities of relying exclusively on biofuels for current and projected energy needs – Land use: competing needs of providing food vs. fuel, do we have capacity to provide the necessary amount of biofuel. Alternative sources for biodiesel production: waste produced from food production or forestry.**

** Teaching resources for ideas about chemistry, are available on ACS website: http://highschoolenergy.acs.org/content/hsef/en.html

Lessons learned

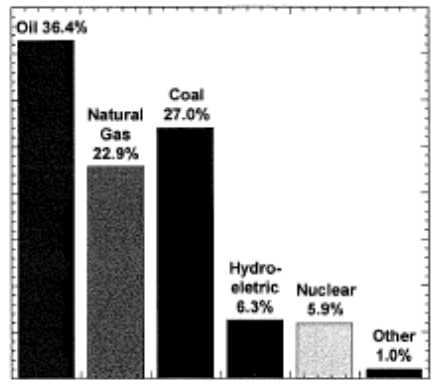
- For university-based researchers looking for school partners, it may be difficult to get responses from schools that are "cold-called." Using preexisting relationships with local schools through faculty, students or staff can be fruitful.
- Teachers appreciated that the lesson is self-contained and that volunteers take care of everything so the only prep for them is preparing students for lesson/experience.
- Most appropriate for general chemistry or physical sciences students – usually freshmen.
- Requires many volunteers and quite a bit of coordination. Volunteers were recruited from grad students and postdocs from department. Some preparation is provided.
- Needs some equipment probably not available at schools: Erlenmeyer flasks (125 ml) and heated stir plates. Do NOT use open flames such as Bunsen burners due to the volatility of the biodiesel. We paired students up so one each for every pair. We bought flasks for the exercise, but were able to check out the stir plates from the undergraduate lab stockroom.
- The oil can be difficult to clean. Be sure to use plastic boxes lined with absorbent pads for storing and transporting the oil. Use trays with absorbent pads on the benches.

ARE BIOFUELS A GOOD SOLUTION TO OUR ENERGY PROBLEMS?

Why Alternative Fuels?

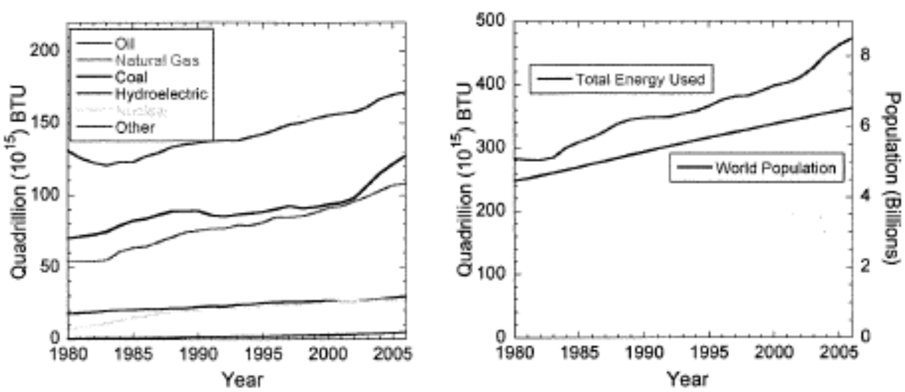
Gas, oil, and coal are the dominant fuels that power human life. 86% of all energy used by humans is derived from these fossil fuels. Estimates for exhausting the known reserves of oil and coal predict them to be depleted within the next 50 years.[1] These are resources that have been formed over millions of years and they may be consumed after only 150 years of industrialization. Because the demand for energy steadily increases with the growth of the human population, there must be an alternative source of energy for us continue living as we currently do.

% of Total Energy Used in 2006[2]



Other = Solar, Wind, Wood, Geothermal, Biofuels

World Energy and Population Trends for 1980-2006[2]



Issues to Consider When Thinking about Alternatives

Scientist and engineers have developed technology to harness energy from many other natural resources such as water, the sun, wind, and agricultural resources, and these alternatives are already used to provide some of our energy needs, as shown in the above bar graph. Such alternative sources of fuel are considered to be sustainable because they are renewable and relatively nonpolluting. Increasing their usage will reduce our dependence on gas, oil, and coal; however, there are practical limitations that hinder the global utility of each of the alternative fuels listed above. In some cases, as in the case of solar energy conversion, more efficient and affordable technology is required before it can be used to provide energy for the worldwide population. In other cases, limited and inconsistent global supply of the resource is available. (For example, wind cannot be used to power the entire planet.) Biofuels are particularly controversial because their usage competes with our food supply.

Do you think it is a *good* idea to use something we consume as food (vegetable oil or corn) to fuel our society? Why or why not?

1. *BP Statistical Review of World Energy June 2006*
2. Energy Information Administration *International Energy Annual*, 2006