There's a lot of corn in the Midwest but can we use it to fly?

Grade Levels: 6-9
Lesson Length: Part II Making Biodiesel 1-2 class periods

Problem Challenge: There is a lot of corn in the Midwest but can we use it to fly?

An effect of global climate change is that the Midwest is now isolated from the rest of world. Your team of scientists needs to find a way to provide sustainable fuel sources for transportation because there is no more gasoline. Without fuel, there is no way to get water, food, and medical supplies around the region.

Fortunately, there is a lot of wind, a lot of good soil, plenty of sun in the summer, and big bodies of water. But is there anything that will power a car or an airplane? Is there anything that will move stuff? And will it do these things without producing the greenhouse gases (GHG) that make climate change even worse?

Lesson Overview

Part II Making Biodiesel – After looking at and analyzing data in Part I, students review energy concepts and use lab techniques to make biodiesel fuel. Then they test and identify properties of several fuels. Fuel data will inform students as they work in teams or pairs to propose solutions to the Midwest's transportation problems. Students want to find a transportation fuel with low CO_2 emissions. They discovered earlier that plants can be converted into fuels.

Standards

NGSS-2013.MS-ETS1-1 and HS-ETS1-1

- Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. (MS)
- Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants. (HS)

Objectives

- Students will describe and interpret graphical information.
- Students will analyze characteristic properties of fuels.
- Students will synthesize data from different sources to reach conclusions.
- Students will recognize that plants can produce fuel.

PART II: MAKING BIODIESEL

Materials

Teacher Note: Decide whether student groups will produce biodiesel from different cooking oils. If so, make sure to purchase and include them in the materials. Students might choose an oil, hydroxide, or alcohol. The assignment can be per group, or the whole class can use the same ones. A source that can be used to locate supplies is:

http://www.cynmar.com/SearchByKeyword?word=green%20chemistry

Per Class –

- Balance
- Weigh boats (at least 1 per group to measure potassium hydroxide or sodium hydroxide)
- Permanent, fine-tipped markers for labeling storage jars

Per Student –

- Student journal and/or copies of Student Page: Making Biodiesel (see p.11)
- Gloves
- Goggles
- Lab apron

Per Group –

- Copies of Student Page: Materials – Making Biodiesel (see p. 8)
- Copies of Student Page: Procedure – Making Biodiesel (see pp. 9-10)
- 250 mL beaker (×2)
- 25 mL or 50 mL graduated cylinder
- 250 mL graduated cylinder
- Thermometer—stirring or digital
- Timer
- 125 mL vegetable (soy) or other cooking oil, such as corn or canola (providing several choices of cooking oil allows students to choose the one that is most interesting to analyze)
- 25 mL methanol or ethanol* (either methanol or ethanol can be used. As with oils, letting students chose the alcohol for their experiment is another opportunity to analyze differing results. This also increases autonomy in the experimental design process)
- Hot plate and stir rod or magnetic stirring hot plate (biodiesel can be produced without heat – using either a stirrer or just stirring by hand, but

it will take several hours longer, and by then you will have to be concerned about the alcohol evaporating)

- 1.2 g solid potassium hydroxide (KOH) or sodium hydroxide (NaOH)*
- Small bottle (at least 30 mL) with tight-fitting cap
- Small funnel (that fits inside the mouth of the small bottle)
- Canning jars or solution bottles (with lids) for storing the biodiesel produced
- 1 or 2 labels for each jar

***SAFETY ALERTS**


Methanol and ethanol fumes are poisonous and highly flammable. Avoid breathing in any vapors when working with these substances. Work in a well-ventilated area or under a fume hood, and be certain that there are no sources of open flames.


Sodium hydroxide and potassium hydroxide are corrosive. Always wear gloves and avoid direct contact when handling these substances.

Teacher Setup and Preparation

Print copies for students:

- Student Page: Making Biodiesel p. 11
- Project or post: Comparison of GHG from Fuels p. 12 and Fuel Chemistry p. 14

Teacher Strategy: This lesson outline includes background information. You may choose to share it with students as readings or lecture with discussion before or after the lab. There is also significant “wait time” during the process of making biodiesel, so some of the information may be shared and discussed during the lab.

How to Prep the Lab:
Making and Testing Biodiesel – Make Crude Biodiesel with a 2-Phase Reaction Process

1. Use the materials list to make sure there are sufficient amounts of the class, student, and group materials.
2. Decide if students will choose an oil, sodium hydroxide or potassium hydroxide, and ethanol or methanol. If so, purchase sufficient amounts of all reactants and include discussion in the pre-lab.
3. The students can simply decant by carefully pouring off the biodiesel layer (top layer) into another container.

4. Be sure to determine an appropriate safe disposal method of the glycerol that is discarded in step 20 of the procedure (regulation will vary per school district). Inform the students of the correct way to dispose of this waste.
5. Remind students to clearly label the final biodiesel product jars with the lab team names, the date, and the type of oil, alcohol, and hydroxide salt (especially if groups used different reactants).

Accessing Prior Knowledge

Pre-lab discussion – Briefly review concepts and ideas to give the lab context for your students.
Ask the students:

- Why are you learning about biofuels?
- Why is biodiesel important to the discussion
- What do you know about biodiesel?
- What do you think you know?
- What are you puzzled about?
- What do you need to explore?

Students should record their responses in their journals and share their ideas with the whole group. After giving students time to consider their responses, the teacher may choose to incorporate the following embedded questions. Many students may not know very much about biodiesel.

Embedded Questions:

- What is biodiesel?
- How is it made?
- What are the pros and the cons of using biodiesel as a fuel?
- How do properties of biodiesel compare to those of other fuels?
- What types of oil can be used to make biodiesel?

Teaching Strategy**:** Use the questions above to facilitate learners' development of understanding what they know and what knowledge they might gain from today's lab. In the best case, students will ask these questions. For younger groups the questions might be more basic, probing for "what is a property", for example.

Project Image p. 12: Making and Testing Biofuels: Chemistry of Fuels
On this image the students will observe the molecular structures of biodiesel, petroleum-based diesel, and vegetable oil.
Ask students:

- What do you SEE?
- What do you THINK?
- What do you WONDER?

Have students record their responses to each of these questions in their journals, share out responses, and record them on class document.

Student sample responses are as follows:

Students may **SEE…**

- All of these molecules are made of carbon, hydrogen, and oxygen.
- Biodiesel and diesel molecules are very similar structures
- Students may come to infer that this is why diesel engines can burn biodiesel with virtually no modifications to the engine (apart from replacing some rubber tubing, which may become soft and break down with biodiesel).
- Vegetable oil is like three biodiesel molecules put together (it is a *tri*glyceride), so it is very large.
- In addition, the biodiesel and vegetable oil molecules contain ester groups, but the petroleum-derived diesel molecule does not.
    - *Esters* are *organic compounds* composed of an *organic acid* and an *alcohol.* An image of an ester is circled and identified on the image of a vegetable/biodiesel molecule.

Teacher Note: This is not an essential idea for the lesson and if your students have little background in chemistry, you can give them the name for the structure, acknowledge that it is there, and move on. This would not be part of an assessment, then.

For middle school students, questions to move discussion forward might be:

- What do you suppose the lines represent? (*connections, bonds*)
- What do you notice about the biodiesel molecule? (*possible answers: the 2 lines between carbon and oxygen, all carbons have 4 bonds*)
- When there is a double line, what might it represent? (*2 bonds between the same two atoms*).
- Would you expect the double bond between carbon and oxygen to be stronger than the single bonds in the diagram? Why or why not? (*yes, a double bond holds the two atoms tighter than a single bond*)
- Looking at the vegetable oil molecule, what do you notice? (*it's huge, it has 3 main parts that look exactly alike, the CH in the middle at the end doesn't have a subscript 2 but the others do*)

Students may **THINK….**

- Large vegetable oil molecule makes it very "thick" or viscous, it would be difficult to use as engine fuel. Maybe it would gum-up the engine. (The students' context may include food such as salad dressing)
- Large vegetable oil molecule would not ignite easily or burn efficiently.

Students may **WONDER…**

- How is vegetable oil made into biodiesel?

Exploring the Phenomenon: Laboratory Experience

In this lab the students will be making biodiesel from vegetable oil.

Review Safety Rules!

1. Explain, demonstrate, and check the following – long pants, closed shoes, hair back, goggles, sleeves pulled back, what to touch, what not to touch, tasting, smelling, observing.
2. Collect safety information/MSDS sheets about each of the fuels being tested.

The Laboratory Investigation: Making Biodiesel

See the lab procedure on the student page located at the end of this activity Student Handout: Procedure – Making Biodiesel (pp. 9-10).

Once you have completed the introduction, preface the lab by explaining that one way to produce biodiesel fuel is from plant-based oils. In this lab the students will be using vegetable oil.

> Ask the students:
> What are some different types of vegetable oil? What are the various raw sources for these oils?
> After asking the questions above, ask students to check the ingredient list on the bottles to determine what is the type of "vegetable oil" you have provided for them. Have students record this information in their journals. Remind students to use their journals to record the purpose, materials, methods, observations, data, analyses, and conclusions from the following lab activity or use the provided Student Lab Sheet on p. 11.

Students will conduct this lab by following the step-by-step instructions provided on the Student Handout: Procedure – Making Biodiesel pp. 9-10. In this portion of the lab, the students will be completing the transesterification process. They will begin with a triglyceride, such as corn oil, which they will mix with an alcohol and a catalyst. Doing this separates the fatty acid tails from the glycerol and the new product will be an ester.

Remind students to record any observations they make as they mix solutions such as physical properties (e.g. color, odor, consistency, and layers of separation). At various points students will have to set a timer for 20 minutes while the oxide solution mixes with the oil over heat. You may choose to use this time to have students read background information or complete and participate in discussion questions.

At this point, students will have made a crude form of biodiesel.

With enough time for clean-up and discussion, announce that students should stop the experiment after completion of the initial steps (Mix, heat, stir. Decant or use separatory funnel) so that their fuel can sit overnight to further purify.

Making Sense

In this activity there is one main scientific principle that should be addressed: Fuel can be made from plants. Students should arrive at this principle via a pathway similar to: "Biodiesel is made from plants, biodiesel is a fuel, so plants can be made into fuel." The teacher can ask the students to name some types of vegetable oil as well as the various raw sources for such oils. Then the students complete the laboratory procedure which chemically converts the vegetable oil to biodiesel. Thus, students have collected evidence which supports the principle that biodiesel is made from plants.
The following list of questions could be used during the time students are waiting for their mixtures to form biodiesel, or the teacher might choose to ask them when students have completed the investigation.

Ask the students:

- What are the advantages and disadvantages of biodiesel? (*Answers will vary. Students will likely recognize that biodiesel is a renewable fuel because it can always be grown. Students may also consider the total (net) carbon emissions released by each of the fuels and consider that biodiesel should have less net emissions because the source of fuel consumed CO_2 while it was growing.*)
- How does biodiesel compare to other fuels in terms of GHG emissions? (*See Comparison of GHG from Fuels on p. 15 – there's a lot more CO_2 from kerosene than from biofuel even though biodiesel has more carbons.*)
- What surprises you about making biodiesel? (*Answers will vary but students should recognize that producing liquid biodiesel from solids is a fairly simple process.*)
- How can you use this information to help you solve the problem? (*Answers will vary*)
- What new questions do you have? (*Answers will vary*)

Student Handout: Materials - Making Biodiesel

Per Class –

- Balance
- Weigh boats (at least 1 per group to measure hydroxide)
- Permanent, fine-tipped markers for labeling storage jar

Per Student –

- Student Journal OR a copy of Student Page: Making Biodiesel
- Gloves, Goggles, Lab apron

Per Group –

- Copies of Student Page: Materials – Making Biodiesel (see p. 8)
- Copies of Student Page: Procedure – Making Biodiesel (see pp. 9-10)
- 250 mL beaker (×2)
- 25 mL or 50 mL graduated cylinder
- 250 mL graduated cylinder
- Thermometer—stirring or digital
- Timer
- 125 mL vegetable (soy) or other cooking oil, such as corn or canola
- 25 mL methanol or ethanol*
- Hot plate and stir rod or magnetic stirring hot plate
- 1.2 g solid potassium hydroxide (KOH) or sodium hydroxide (NaOH)*
- Small bottle (at least 30 mL) with tight-fitting cap
- Small funnel (that fits inside the mouth of the small bottle)
- Canning jars or solution bottles (with lids) for storing the biodiesel produced
- 1 or 2 labels for each jar

***SAFETY ALERTS**

Methanol and ethanol fumes are poisonous and highly flammable. Avoid breathing in any vapors when working with these substances. Work in a well-ventilated area or under a fume hood, and be certain that there are no sources of open flames.

Sodium hydroxide and potassium hydroxide are corrosive. Always wear gloves and avoid direct contact when handling these substances.

Student Handout: Procedure – Making Biodiesel

Make Crude Biodiesel with a 2-Phase Reaction Process

1. Using a graduated cylinder, obtain 25 mL of an alcohol, as directed.
2. Obtain a small bottle with a lid and a funnel. Remove the cap of the small bottle and, using a funnel, carefully pour the 25 mL of the alcohol into the bottle, and replace the cap.
3. Weigh out 1.2 g of solid sodium or potassium hydroxide, as directed. The hydroxide will serve as a catalyst for the reaction.
4. Remove the cap from the small bottle containing the alcohol and add the hydroxide salt.
5. Place the cap back on the small bottle of alcohol and hydroxide (hydroxide salt) making sure the cap is on tight. Shake the bottle for about 1 minute.
6. After 1 minute, loosen the cap of the bottle to release pressure that may have accumulated.
7. Tighten the cap on the bottle and shake it for another minute.
8. Loosen the cap after 1 minute to release pressure, then tighten the cap and shake the bottle again. Repeat this cycle in 1-minute intervals for as long as needed for the hydroxide salt to completely dissolve. **Be sure to loosen and retighten the cap after each cycle!**
9. When the hydroxide salt is completely dissolved in the alcohol, the solution is now referred to as *potassium (or sodium) methoxide* if the alcohol was methanol and *potassium (or sodium) ethoxide* if the alcohol was ethanol. The oxide will react with the oil and will produce biodiesel esters and glycerol.
10. Use a graduated cylinder to measure 125 mL of vegetable oil. Pour the oil into a clean 250 mL beaker.
11. Place the beaker with oil on a hot plate, preferably a magnetic stirring hot plate. If you are using a magnetic stirring hotplate, add a magnetic stir bar and set the stir speed to medium (so the contents will mix well but will not splash).
12. Use a graduated cylinder to measure out 20 mL of the oxide solution from the small bottle. Be sure to leave the remaining 5 mL in the bottle for later use and tightly replace the cap.
13. Carefully add the 20 mL of oxide to the oil in the beaker while stirring. If you are not using a magnetic stirrer, use a stir rod to continuously stir the mixture at a quick rate.
14. Turn on the hotplate and heat the oil to about 55–60°C. Use a thermometer to check the temperature very frequently. When the oil is 55–60°, reduce the heat as needed to maintain the temperature in that range.
15. At this point, make sure you start your timer for 20 minutes.
16. Keep stirrin, monitoring the temperature, and adjusting the heat level to maintain the temperature range of the mixture for 20 minutes.
17. At the end the 20 minutes, quit stirring and turn off the heat.

18. Leave the beaker to sit undisturbed for at least 15-20 minutes. While it sits, you should see the oil and oxide mixture separate into two layers:
    - The top layer is the biodiesel esters
    - The bottom layer contains the glycerol, the catalyst, and leftover alcohol
19. Next, you will slowly and carefully decant off the top layer of biodiesel esters into a clean 250 mL beaker, leaving the bottom layer of glycerol and residual substances behind.
20. Place the 250 mL of biodiesel on the hot plate, and repeat the procedure above but using only the remaining 5 mL of oxide (not 20 mL as before). Again, heat the oil mixture to 55–60°C while stirring continuously. This is the second phase of the reaction, which converts remaining triglycerides that were not converted in phase one. Don’t forget to set a timer for 20 minutes.
21. While phase two of this reaction is occurring on the hot plate, empty the glycerol out of the 250mL beaker you used in phase one—your instructor will direct you regarding where to place the glycerol mixture—and thoroughly wash and dry the 250 mL beaker.
22. At the end of the 20 minutes, turn off the hot plate and allow the oil mixture to sit undisturbed for at least another 20 minutes, during which time two layers should form.
23. Separate the biodiesel esters from the glycerol layer, as before, and place the crude biodiesel in the clean 250 mL beaker with the biodiesel that was already collected in Phase 1.
24. Transfer the crude biodiesel to canning jars or sealed solution bottles for storage.

Note: Be sure to clearly label the jars. Include the lab team’s names, the date, type of oil, hydroxide, and alcohol.

Name________________________________ Class___________ Date________

Making Biodiesel

Objectives:

1. Compare models of the molecular structure of biodiesel, diesel, and vegetable oil
2. Produce biodiesel through a chemical reaction between an oil and an alcohol.

Introduction:
Look at the image of the molecular structures of biodiesel, diesel, and vegetable oil on p. 12 and fill in the table below:

See	Think	Wonder

Exploring the Phenomenon: Laboratory Experience
Use the space below to record any observations or notes during your investigation. Particularly notice if there are any changes in the substances.
Suggestions:

- Complete a table comparing properties before and after mixing substances.
- Draw and label a model showing the substance before and after.

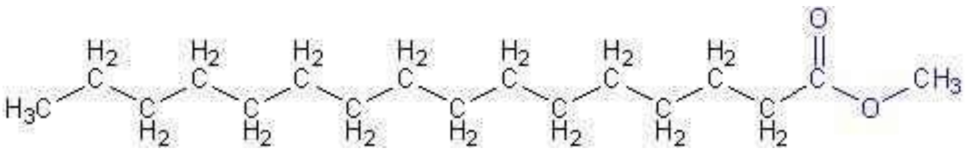
Substance	Before	After
(alcohol)		
(hydroxide)		
(oil)		

Projected Image

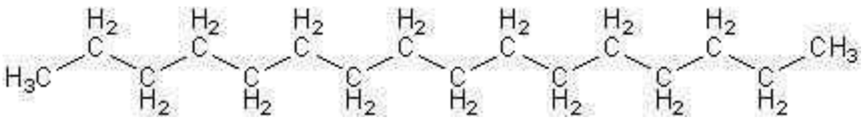
Making and Testing Biofuels: Chemistry of Fuels

Below are models of typical molecules of biodiesel, of petroleum-derived diesel, and of vegetable oil. (Images from http://www.goshen.edu/chemistry/biodiesel/chemistry-of/)

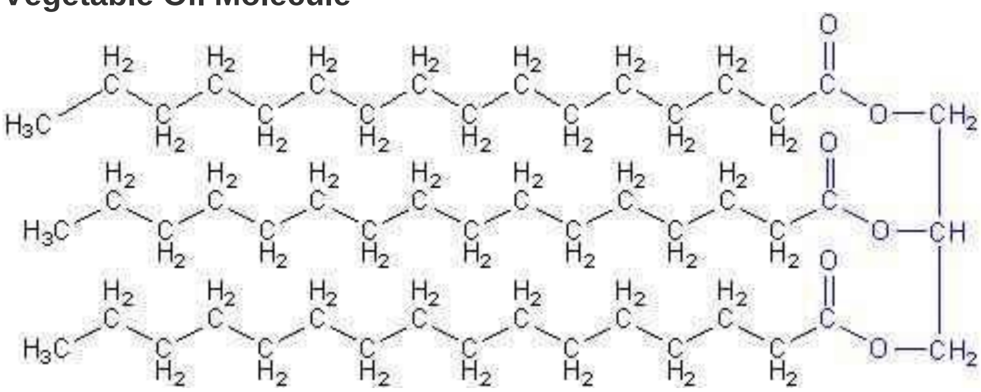
Biodiesel



Diesel



Vegetable Oil Molecule



Properties of Fuels and Oils

Part II and Part III

Making and Testing Biodiesel

Substance	Clarity	Color	Odor	# C atoms	Energy density	Spot test	Viscosity

These properties of substances define them and make it easier to compare them. Questions to consider:

Which fuels might be the best for cars? For airplanes? For heating and cooking? Why?

What is the relationship between carbon atoms per molecule (how they are constructed) and properties (how they act) of substances?

Comparison of Carbon Dioxide Given Off During Combustion of Fuels

Methanol: $CH_3 OH + O_2 \rightarrow CO_2 + H_2O$

Methanol BALANCED: $2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$

Ethanol: $C_2H_5OH + O_2$ --> $CO_2 + H_2O$

Ethanol BALANCED: $2C_2H_5OH + 6O_2 \rightarrow 4CO_2 + 6H_2O$

Propanol: $C_3H_7OH + O_2 \rightarrow CO_2 + H_2O$

Propanol BALANCED: $2C_3H_7OH + 9O_2 \rightarrow 6CO_2 + 8H_2O$

Butanol: $C_4H_9OH + O_2 \rightarrow CO_2 + H_2O$

Butanol BALANCED: $C_4H_9OH + 6O_2 \rightarrow 4\ CO_2 + 5H_2O$

Biodiesel: $C_{19}H_{36}O_2 + O_2 \rightarrow CO_2 + H_2O$

Biodiesel BALANCED: $C_{19}H_{36}O_2 + 27O_2 \rightarrow 19CO_2 + 18H_2O$

Kerosene: $C_{12}H_{26} + O_2 \rightarrow CO_2 + H_2O$

Kerosene BALANCED: $2C_{12}H_{26} + 37O_2 \rightarrow 24CO_2 + 36H_2O$