Biofuels from plant oils

Focus question	How do plant oils become fuel?
Learning target	Students will produce biomass-based diesel from corn and soybean oils.
Vocabulary	Transesterification, biodiesel, biodiesel, petroleum diesel, miscible, glycerin, catalyst, ester, fatty acid chains, glycerol, hygroscopic

HS-PSS 3-3 Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

Performance expectation HS-PSS 3-3	**Classroom connection:** Students create biomass-based diesel from oil and test its performance using various methods.

Science and engineering practices

Constructing Explanations and Designing Solutions	**Classroom connection:** Students conduct research to determine the difference between biomass-based diesel created from corn oil (biodiesel), soybean oil (biodiesel), and petroleum diesel, then construct an explanation for which plant oil makes a better fuel source when compared to petroleum diesel under various conditions.

Disciplinary core ideas

PS3.D: Energy in Chemical Processes	**Classroom connection:** Students create and convert biomass-based diesel from plant oils into different forms of energy.
ETS1.A: Defining and Delimiting an Engineering Problem	**Classroom connection:** From the research and production process, students determine if there is a better biomass-based diesel, considering issues such as risk and quantification from their production process.

Cross-cutting concepts

Energy & Matter	**Classroom connection:** Classroom connection: Students evaluate the biomass-based diesel on the basis of energy flows and storages.
Influence of Science, Engineering and Technology on Society and the Natural World	**Classroom connection:** Students evaluate benefits, costs, and risks.

This lesson may be used independently or as a follow-up to the previous lessons in the Energy and Biofuels unit. Students will be researching plant oils, creating their own biomass-based diesel from plant oils, and evaluating the results from their process.

Background

Diesel engines such as trucks, tractors, and heavy motors rely on No. 2 diesel for power. Diesel is commonly made by petroleum distillation. Renewable substitutes for petroleum diesel are growing in popularity. These biofuels can be easily made from corn, soy and other plant oils, animal fats, and waste grease through chemical reactions.

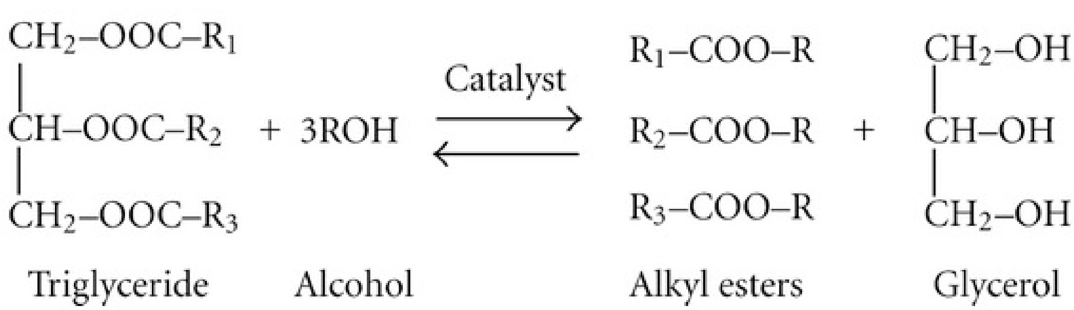
Biofuels are liquid or gaseous fuels commonly used for transportation. These are referred to by the United States Department of Agriculture as “drop-in fuels”, requiring no engine modification when blended with refined petroleum products. Biofuels derived from plant materials such as corn and soy are among the most rapidly-growing renewable energy technologies. While this fuel has less energy per unit volume than traditional diesel fuel, it results in much less air pollution due to its higher oxygen content and lack of "aromatic compounds” and sulfur.

Biofuels from plant oils include biodiesel and renewable diesel (`eia.gov/energyexplained/biofuels/`).

- **Biodiesel** is the term used for fuel made from soybean oil and is typically blended with petroleum diesel.
- **Renewable diesel** refers to biofuel mainly from corn oil and can be used as a replacement fuel with no blending.

Plant oils are triglycerides that have a standard structure. A molecule of any given vegetable oil consists of two parts, a glycerol backbone and three distinct fatty acid chains that stem from the glycerol. Biodiesel is produced using the chemical process known as transesterification. Transesterification occurs when one type of ester, an oil molecule in this case, exchanges an R group with an alcohol.

Making biodiesel in the classroom requires methanol. We will also use a catalyst, potassium hydroxide, to speed up the reaction. The combination of catalyst and methanol is called methoxide. The end product is a combination of biomass-based diesel, unreactive methanol, glycerin, and soap.



Koohikamali, Sara & Tan, Chin & Ling, Tau. (2012). Optimization of Sunflower Oil Transesterification Process Using Sodium Methoxide. TheScientificWorldJournal. 2012. 475027. 10.1100/2012/475027.

The products separate into two layers with the biodiesel on top. The biodiesel is removed and washed, then it is ready for product evaluation. In industrial applications, the oil is then refined through a process that we cannot replicate in the lab. Biodiesel undergoes a refinery process similar to petroleum diesel.

Renewable diesel results in biodiesel that is stable at low temperatures using a different process that creates a reaction with the feedstock and hydrogen called hydrotreating. Gasification, pyrolysis, and other biochemical and thermochemical technologies can also be used to create renewable diesel. Renewable diesel has lower production volumes than biodiesel in the U.S.

Another sustainable energy option is ethanol. Ethanol is made mostly of corn starch from kernels through fermentation and distillation, and is by far the most significant biofuel in the United States. Interested in ethanol lessons? Find more at nourishthefuture.org/curriculum/energy-biofuels/hs.

Materials

- Methanol or HEET (yellow bottle)
- Sodium hydroxide or Potassium hydroxide
- Glass jar/lid
- 200 mL beaker
- Magnetic stir bar
- Hot plate/stir option
- Separatory funnel, 250 mL or pint-sized jar with lid
- Ring stand with ring (not needed if using jars)
- Graduated cylinder
- Serological pump and pipettes
- Distilled water
- Weigh boats
- Scales
- Corn oil
- Vegetable (soybean) oil
- Other oils, if desired
- Disposable pipettes

Materials for testing

- Pop-pop steam boats (1 per group)
- Lighter or matches
- Disposable pipettes
- Clear test tube
- Liquid food coloring
- Microtubes
- Access to refrigerator/freezer
- Balance/scale
- pH test strips or pH meter

Teacher preparation

If you need a primer on diesel engines and fuel, there are several youtube.com videos that describe the use of diesel, how diesel engines operate and this one even includes a biodiesel discussion. *This one is NOT appropriate for students,* but gives a comprehensive overview: youtu.be/4YT0WcI7hjk

This video could be assigned to help explain how a four-stroke diesel engine works (no words, so students need to read the descriptions). youtu.be/fTAUq6G9apg

This lab may be completed using either separatory funnels suspended on ring stands or glass jars. The difference will be in the way the layer of glycerol will be removed. In separatory funnels, the stop cocks can be opened to allow the glycerol and waste from washing to flow out of the bottom. If using glass jars, the waste must be removed from the bottom. This can be done with disposable pipettes or using a pipette pump and serological pipettes.

Both sodium hydroxide and potassium hydroxide work in this procedure when mixed with methanol to make methoxide. HEET (yellow bottle), a fuel additive available from auto part stores and most discount stores, may be substituted for methanol.

1. Ask students to tell you what they know about the various types of diesel fuels (biodiesel, biodiesel and petroleum diesel). Have them choose one of the fuels to research: where does it come from, how is it created/refined, what is it being used for, what benefit does it provide over the other forms of fuel, estimated supply, etc.
2. Begin setting up for the lab by determining which materials you will use.
3. Divide students into groups to create biodiesel using one or more types of plant oil.
4. Detailed instructions are included on the student handout. Safety notes:
    - Methanol should be handled under a fume hood or in a well-ventilated area if a fume hood is not available.
    - Sodium and potassium hydroxide can be caustic, so use caution when handling or provide gloves for students.
    - Keep the hydroxide tightly capped; otherwise, it will attract moisture from the surrounding air.
5. This activity will take 2–3 days depending on how long you allow in between washings. Students can be completing research on fuels while waiting for settling.

Pop-pop boat preparation

1. Remove the spoon/candle holder from the boat. Prepare the boat for running by using a disposable pipette to add water to the pipes on the underside of the boat. This water is necessary for propulsion of the boat through the water.
2. Remove the candle from the spoon or holder. You will need a wick in a holder or a piece of string to light.
3. Add 1 ml of your fuel into the spoon/holder. Add a wick.
4. Light the wick, then insert the spoon/holder into the hull of the boat under the tin plate. *Be careful not to push it under the plate too far or the flame will not stay lit.
5. It may take a few moments for the boat to heat enough to make steam that will propel the boat in the water. You will hear the pop pop that indicates the boat will move.
6. Time how long the fuel burns or set up races against other groups to test speed.

Testing biodiesel is another step students can take to determine the quality of the fuel they produced. There are several tests that students can perform. Directions for each test are included on the student document.

Student handout

Procedure

Part 1: Making biodiesel (Day 1)

1. Under a fume hood, measure out 30 mL of methanol or HEET and add to glass jar, then seal jar quickly.
2. Weigh out 0.75 g of KOH (potassium hydroxide) and quickly add it to the jar of methanol. Seal jar immediately and shake to dissolve. Make sure to recap the KOH because it is hygroscopic. Your mixture is now called methoxide.
3. At the lab station, in a clean beaker, warm 75 mL of oil sample to 50° C.
4. Add warmed oil sample to methoxide mixture in jar.
5. Add magnetic stir bar to the jar; loosely place lid back on jar; set stir to high speed and stir for 15 minutes. (Alternatively, tighten the lid, then shake vigorously for 15 minutes.)
6. Allow to sit for 24 hours.

Data for Part 1 (Day 1): visual observations from part 1 of Making biodiesel

1. Immediately upon adding the methoxide, what did you notice about the oil? Was there a change in the color of the sample?

Possible answers: Answers will vary depending on which fuel and catalyst used.

2. What did the solution look like after it began stirring?

Possible answers: Answers will vary depending on which fuel and catalyst used.

Part 2 (Day 2)

Data from Washing biodiesel

1. Now that the biodiesel has rested for 24 hours, describe your sample.

Possible answers: There should be observable layers in the sample. The glycerin portion will be on the bottom due to density, while the “fuel” layer will be on top.

2. Record the following characteristics of your biodiesel sample: color, consistency, and odor.

Possible answers: Answers will vary depending on which fuel and catalyst used.

Differentiation

Other ways to connect with students with various needs:

- **Local community:** Students may investigate plant oils that are produced in their local area or visit grocery stores to see the range of oils on the shelf.
- **Students with special needs (auditory/visual/language/reading):** Students with special needs (auditory/visual/language/reading): Students may be paired with other students to investigate plant oils for other uses such as bioproducts such as polymers, cleaning agents, lubricants, paint additives, etc. See World of Corn (`worldofcorn.com`) and soy biobased (`soybiobased.org/videos`).
- **Extra Support:** Students may be grouped to allow all students to participate. Lab stations may be pre-set. Students may need measuring help or procedural aids. Group members may be tasked with only specific steps of the lab based on their abilities.
  This infographic represents the process of corn flour breakdown into glucose for fermentation.
- **Extensions:** Students may research the current commercial process of ethanol and biodiesel production and uses of any generated coproducts. Visit: `afdc.energy.gov/fuels/emerging_hydrocarbon.html` for additional information.

Assessments

Rubric for assessment

Skill	Developing	Satisfactory	Exemplary
Explained the difference between various fuels	Successfully compared two types of fuel	Three types of fuel are compared	Thorough comparison of all fuels and other variables
Collected evidence from making biomass-based diesel out of plant oils	Evidence only from own lab group	Evidence from biofuels production from at least two groups used as evidence	Evidence included from biofuel production of all class groups
Calculated the percent yield of biomass-based diesel	Error in calculation of yield	Correct calculation of yield performed	Calculation of yield for each biofuel tested and with any other introduced variables
Constructed an explanation for which plant oil makes a better fuel source under various conditions	Incomplete explanation (either evidence or reasoning is missing)	Explanation includes one claim and evidence to support the claim and one reason	Explanation includes all collected evidence to support the claim with sound reasoning connecting to energy conversion

Rubric for self-assessment

Skill	Yes	No	Unsure
I can explain the difference between petroleum diesel, biodiesel, and biodiesel.			
I can explain the process of transesterification.			
I can perform at least three procedures to test the quality of biodiesel.			