

# Biofuels from plant oils

<b>Focus question</b>	How do plant oils become fuel?
<b>Learning target</b>	Students will produce biomass-based diesel from corn and soybean oils.
<b>Vocabulary</b>	Transesterification, renewable diesel, 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.**

<b>Performance expectation</b> HS-PSS 3-3	<b>Classroom connection:</b> Students create biomass-based diesel from oil and test its performance using various methods.
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## Science and engineering practices

<b>Constructing Explanations and Designing Solutions</b>	<b>Classroom connection:</b> Students conduct research to determine the difference between biomass-based diesel created from corn oil (renewable diesel), 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.
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## Disciplinary core ideas

<b>PS3.D: Energy in Chemical Processes</b>	<b>Classroom connection:</b> Students create and convert biomass-based diesel from plant oils into different forms of energy.
<b>ETS1.A: Defining and Delimiting an Engineering Problem</b>	<b>Classroom connection:</b> 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

<b>Energy &amp; Matter</b>	<b>Classroom connection:</b> Classroom connection: Students evaluate the biomass-based diesel on the basis of energy flows and storages.
<b>Influence of Science, Engineering and Technology on Society and the Natural World</b>	<b>Classroom connection:</b> 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.

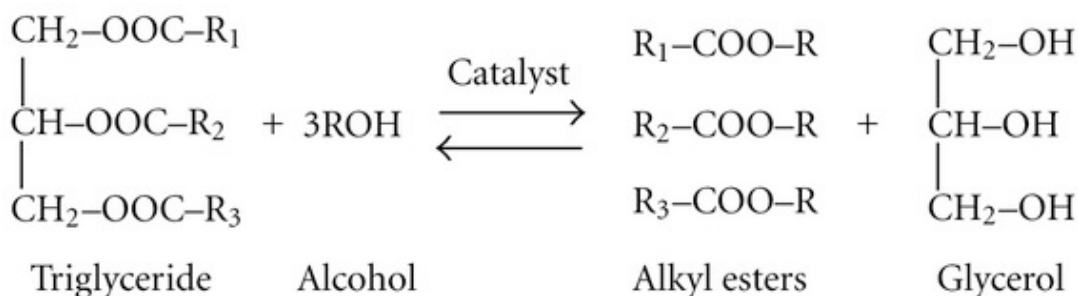
## Background

Diesel engines such as trucks, tractors, and heavy motors rely on No. 2 diesel for power. Diesel is commonly made from petroleum distillation. Renewable substitutes for fossil 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** refer to 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 modification to engines. Biofuel derived from plant materials is among the most rapidly-growing renewable energy technologies. **Ethanol**, made mostly from corn starch from kernels using a process called fermentation, is by far the most significant biofuel in the United States. The remaining amount is **biodiesel**, which is made from vegetable oils (chiefly soy oil) as well as animal fats, waste oils, and greases. ([ers.usda.gov/data-products/us-bioenergy-statistics/](http://ers.usda.gov/data-products/us-bioenergy-statistics/)) Biomass-based diesel fuels include biodiesel and renewable diesel ([eia.gov/energyexplained/biofuels/](http://eia.gov/energyexplained/biofuels/)). Typically, 'biodiesel' is the term used for biomass-based diesel from soybean oil, while 'renewable diesel' refers to biomass-based diesel from corn oil.

Biomass-based diesel burns cleaner than petroleum and is derived entirely from biological sources. Environmental Protection Agency (EPA) research indicates that biomass-based diesel emits 11% less carbon monoxide and 10% less particulate matter than diesel. The Department of Energy and Agriculture found biodiesel reduces net carbon dioxide emissions by 78%. Unlike petroleum diesel, which contains sulfur and carcinogenic benzene, two components regulated by the EPA, biodiesel is nontoxic and biodegradable. They are completely **miscible** with petroleum diesel, which allows for easy blending. Biomass-based diesel can be combusted in any diesel engine, without needing to modify the engine.

Vegetable oils are triglycerides and they 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. Today, we will be making biomass-based diesel with oil and 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.



The synthesis is a simple chemical reaction that produces biomass-based diesel and **glycerol**. The oil is mixed with methanol, while sodium or potassium hydroxide is added as a catalyst. The products separate into two layers with the biodiesel on top. The biodiesel is separated 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 from a new process that creates a reaction with the feedstock and hydrogen called hydrotreating. Consequently, renewable diesel does not have hydrogen in it, whereas biodiesel does. Renewable diesel also has lower production volumes than biodiesel in the U.S.

## Materials

- Methanol
- 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 w/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

## 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](https://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](https://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 with a serological pump with pipettes.

Both sodium hydroxide and potassium hydroxide work in this procedure when mixed with methanol to make methoxide. HEET, 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, renewable diesel 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 biomass-based diesel 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.

# Student handout

## Procedure

### Part 1: Making renewable diesel (Day 1)

1. Under a fume hood, measure out 60 mL of methanol and add to glass jar, then seal jar quickly.
2. Weigh out 1.5 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 150mL 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 renewable diesel

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 renewable diesel

1. Now that the renewable diesel 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.

#### Initial removal of glycerin

1. Drain the glycerin from the renewable diesel into your jar. Using a graduated cylinder, record the amount of glycerin retrieved from sample. *Note: Crude renewable diesel contains impurities such as soap, incompletely transesterified glycerides, and methanol and must be cleaned/washed prior to use).*

#### Wash and dry renewable diesel

1. Using a serological pipette, slowly add a total of 20 mL distilled water down the side of the jar.
2. Pick up the jar and gently rock back and forth for five minutes to wash the renewable diesel. (Do not shake!)
3. Let jar stand and wait 10 minutes for the mixture to separate into two layers. Pipette off the bottom "soapy" layer. Remove soap/glycerin waste into a waste flask or jar.

## 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](http://worldofcorn.com)) and soy biobased ([soybiobased.org/videos](http://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](http://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, renewable diesel, and biodiesel.			
I can explain the process of transesterification.			