

# Combustion of a Renewable and Fossil Fuel: Teacher Manual

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## Goals:

- Students will understand how matter and energy are affected by combustion.
- Students will understand the difference between complete and incomplete combustion.
- Students will understand the energy content and combustion emission differences between diesel and biodiesel fuel.

## Background

Combustion involves a series of chemical reactions between a fuel (i.e. a hydrocarbon, or an organic compound containing only carbon and hydrogen) and oxygen. The result is a major reorganization of both matter and energy.

## Matter

Combustion can be complete or incomplete depending on how much oxygen is present. The diagrams below represent complete combustions, which happens in the presence of ample oxygen. When complete combustion occurs, all of the carbon atoms in a fuel (ie. the diesel and biodiesel molecules below) will be converted to carbon dioxide molecules. Also, the hydrogen atoms that were attached to each carbon atom in the fuel bind with oxygen to form water.

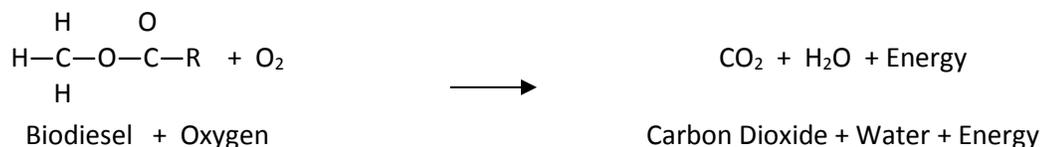
### Complete combustion:



### Complete combustion of diesel:



### Complete combustion of biodiesel:



*Note that R, the hydrocarbon chain, will vary in length depending on the feedstock used to make the biodiesel (it will be greater than 10 carbons).*

When combustion is incomplete (due to lack of oxygen), other products such as carbon monoxide and particulates form in addition to carbon dioxide and water.

*Incomplete combustion:*

**Fuel + Oxygen → Carbon Dioxide + Water + Energy + Soot + Carbon Monoxide**

Incomplete combustion is common. You may have heard of the dangers of carbon monoxide poisoning that are associated with furnaces incompletely combusting natural gas in a low-oxygen environment. You may have also seen the effects of incomplete combustion in a smoky campfire (combusting biomass releases a lot of particulates or soot). *In this lab, you will qualitatively compare the completeness of combustion of diesel and biodiesel by visually examining the emissions produced during combustion.*

## Energy

As you may have noticed in the diagrams above, combustion also releases energy stored in fuel. In the case of a hydrocarbon, the energy was stored as chemical potential energy in hydrocarbon bonds. The more hydrocarbon bonds, the more energy stored in a hydrocarbon molecule. Through combustion, that chemical potential energy is converted to light and heat.

The energy released from the combustion of fuel within the diesel engine drives the car. When diesel or biodiesel has been injected into an engine cylinder and is combined with oxygen taken in through the engine's air intake valves, combustion occurs. The explosion moves the piston which powers the crank shaft. This eventually results in the wheels moving.

A fuel that has more stored energy will mean more miles per gallon and power for the driver. In this lab, you will quantitatively compare the energy contents (by measuring heat of combustion) of biodiesel and diesel using principles of calorimetry.

## Calorimetry

**Calorimetry** is the science of measuring the heat evolved or required in a chemical reaction. In this lab you will construct a simple calorimeter to measure the heat released when combusting diesel and biodiesel. Specifically, you will burn the two fuels in a consistent manner and measure the temperature increase in a known volume of water. If your calorimeter was a closed system, all of the heat released would be transferred to the water. Obviously, some heat in your system will be lost to the environment, but you should still be able to take meaningful relative measurements.

## Materials

- Emptied and cleaned 12-oz aluminum soda cans (two per student group)
- Pencil (one per group)
- Ring stand with ring attached (one per group)
- Oil burners (two per group—one filled with diesel and one filled with biodiesel)
- Small funnel (one per group)
- Lighter (one per group)
- 250 ml Graduated cylinder (one per group)
- Alcohol thermometer (one per group)
- Balance accurate to 0.01g (Weight capacity: ~500 g)
- Ruler
- Calculator
- Marker (for labeling)

## Safety

*Because we are burning fuels, this laboratory is best done outdoors or underneath a fume hood to avoid inhalation of fumes. Also, to protect yourself, make sure to wear goggles and gloves at all times.*

*In addition, it is important to make sure that equipment is clean and that no oil has been spilled over the outside of the burners in order to prevent any accidental flames from forming anywhere besides the wick of the burner.*

## Procedure

Note: You have one oil burner filled with either diesel or biodiesel in front of you. Begin the procedure using that burner. Repeat the procedure using an oil burner filled with the other fuel (you will need to obtain this from another group).

1. Determine the mass of the oil burner and fuel (with the cap on) using the balance. Record the mass in the data table on the next page.
2. Measure 200 ml of water using a graduated cylinder. Using a funnel, pour the water into the soda can. Record the mass of water in the can on the data table (Note: 1 ml H<sub>2</sub>O = 1 g H<sub>2</sub>O at room temperature).
3. Fasten the soda can to the ring stand by placing a pencil through the can tab. Let the can fall through the ring until it is suspended by the pencil on the ring stand.
4. To measure the initial temperature of the water, hold an alcohol thermometer in the water so that it does not touch the sides of the soda can. Record the temperature in the data table.
5. Place burner under can. Adjust the ring height so that the top of the wick is a measured 3 cm below bottom of the can (Figure 1). Center the oil burner under the can.
6. Remove the cap from the oil burner and light the wick using a lighter. (You may need to adjust the ring stand to light the burner. Be sure to quickly reposition after the flame is lit.)
7. Use a thermometer to measure the temperature of the water. Use the thermometer to stir the water periodically.

8. As you burn your fuel make observations on your data table about associated smells, and the nature of the flame and smoke.
9. Continue heating and stirring the water until the temperature has increased by  $\sim 25^{\circ}\text{C}$ . At that point, raise the ring (with the can still attached) and quickly extinguish the flame by placing the burner cap over the wick.
10. Continue to gently stir the water and record the maximum temperature the water reaches.
11. Determine the final mass of the oil burner (with the cap) and the remaining fuel using the balance. Record the final mass in the data table.
12. Note the quantity of soot on the soda can in your data table (under observations).
13. Repeat steps 1-13 with your other fuels.
14. Clean all equipment.

## Data table

Use the following table to record your data and emissions observations as well as data gathered during Data analysis (after Data table). Step by step calculations can be found on the next page.

|   | Biodiesel | Diesel |
|---|-----------|--------|
| Initial water temp. ( $^{\circ}\text{C}$ )                  |           |        |
| Final water temp. ( $^{\circ}\text{C}$ )                    |           |        |
| Change in water temp. ( $^{\circ}\text{C}$ ) ( $\Delta t$ ) |           |        |
| Heat (J, calculated using $q=mC\Delta t$ )                  |           |        |
| Initial mass of oil burner (g)                              |           |        |
| Final mass of oil burner (g)                                |           |        |
| Mass of fuel burned (g)                                     |           |        |
| Heat of combustion (J/g)                                    |           |        |
| Observations:   |           |        |

## Data Analysis

Use the information in your data table to calculate the amount of energy released as heat, heat of combustion (J/g), by diesel and biodiesel.

- 1) For each fuel calculate change in temperature ( $\Delta t$ ) and the mass of fuel burned (g). Record your results into your data table.

$$\Delta t (^{\circ}\text{C}) = \text{Final Temperature} - \text{Initial Temperature}$$

With biodiesel:

With diesel:

$$\text{Mass of fuel burned (g)} = \text{Final mass of oil burner} - \text{Initial mass of oil burner}$$

Biodiesel:

Diesel:

- 2) The amount of heat transferred to the water can be determined by using the following equation:  $q = mC\Delta t$ , where  $q$  is heat in Joules,  $m$  is mass in grams of water,  $C$  is the heat capacity of water (4.18 J/g°C), and  $\Delta t$  is the temperature change of the water in degrees Celsius. Record your results into your data table.

With biodiesel,  $q =$

With diesel,  $q =$

- 3) Calculate the heat of combustion by dividing  $q$  by the mass of fuel of used. Record your results into your data table.

Heat of combustion (biodiesel)

Heat of combustion (diesel)

## Questions

- 1) Where did the energy you measured as heat come from?
- 2) What do these results indicate about the relative energy content of diesel and biodiesel?
- 3) How do your results compare to Argonne Laboratory's heat of combustion results for diesel and biodiesel (see table on the next page)?
- 4) Why do you think your results differ from the Argonne Laboratory results?

| Fuel      | Your heat of combustion (J/g) value | Argonne Laboratory's heat of combustion (J/g) value |
|-----------|-------------------------------------|---|
| Biodiesel |                                     | 40,160  |
| Diesel    |                                     | 45,759  |

- 5) Did you witness complete or incomplete combustion of diesel and biodiesel? How do you know?



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## Background

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## Materials

- 2 – 12-oz aluminum soda cans
- Pencil
- Ring stand with ring attached
- Oil burner (1 Biodiesel, 1 Diesel)
- Small funnel
- Lighter
- 250 ml Graduated cylinder
- Alcohol thermometer
- Ruler
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## Procedure

**Note:** You have one oil burner filled with either diesel or biodiesel in front of you. Begin the procedure using that burner. Repeat the procedure using an oil burner filled with the other fuel (you will need to obtain this from another group).

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- 5) Did you witness complete or incomplete combustion of diesel and biodiesel? How do you know?
  
- 6) According to the US Environmental Protection Agency, biodiesel produces 47% less particulate matter and 48% less carbon monoxide emissions than diesel. Are the EPA particulate matter results aligned with your observations of combustion?
  
- 7) Can you explain the differences in the combustion results described above (Hint: look at the molecular formulas of diesel and biodiesel)?
  
- 8) What are the comparative advantages of using biodiesel instead of regular diesel?