Science 30 Project
Biodiesel—
A Fuel for the Future?
Student Booklet
2008–2009
Biodiesel—A Fuel for the Future?

Table of Contents

<table>
<thead>
<tr>
<th>Part</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Overview</td>
<td>1</td>
</tr>
<tr>
<td>Part 1: Making Biodiesel</td>
<td>2</td>
</tr>
<tr>
<td>Part 2: The Chemistry of Making Biodiesel</td>
<td>9</td>
</tr>
<tr>
<td>Part 3: Does Biodiesel Work in the Cold?</td>
<td>11</td>
</tr>
<tr>
<td>Part 4: A Risk–Benefit Analysis</td>
<td>13</td>
</tr>
<tr>
<td>Extension: Determining the Energy Content of Biodiesel</td>
<td>14</td>
</tr>
</tbody>
</table>
Project Overview

Previous science courses probably taught you that molecules store chemical potential energy, which can be released when chemical bonds in matter are broken and new bonds are formed. Maybe you’ve even completed an experiment to determine the energy in a sample of food or fuel. Whether oil is crude or plant-based — peanut oil, palm oil, olive oil, or canola oil — it has molecules that are often described as “energy rich.”

Rudolf Diesel, the inventor of the diesel engine, demonstrated in 1900 at the world’s fair in Paris that an engine could run on peanut oil rather than petroleum-based fuels.

Considering the current concern over the depletion of crude oil reserves and the growing demand for energy, Diesel was quite a visionary when mentioned, in 1912 that

Even though the use of vegetable oils for engine fuels may seem insignificant today, such oils may become in the course of time as important as the petroleum and coal tar products of the present time.

Diesel’s insight about the potential of plant-based oils as an energy source is being demonstrated by people using waste vegetable oil from restaurants as a fuel in their diesel-engine powered vehicles. Around the world, some governments and some corporations within the energy industry are promoting the production of biodiesel, the fuel produced by the modification of vegetable oils.

The yearly consumption of diesel fuel in North America is 245.5 billion litres, most of it for transportation of goods and people. The production and sale of blended diesel fuels, which contain a percentage of biodiesel (e.g., 20% in the case of biodiesel B-20) mixed with petroleum-based diesel fuel, is a growing industry in Europe, where sources of petroleum-diesel are limited. Concerns about depleting petroleum sources elsewhere in the world, including North America, have forced governments and the oil industry to consider biodiesel as a means to offset some of the demand for petroleum-diesel.

In this project, you will investigate the production and use of biodiesel, focusing on the chemistry of its production, the practicality of its use at low temperatures, the energy changes associated with its use, and the sustainability of this energy source.
Part 1: Making Biodiesel

Biodiesel is an alternative fuel that is made from vegetable and animal oils. It can be used directly in diesel vehicles or blended with traditional petroleum diesel. You will discover during this lab how easy it is to make and store biodiesel. The chemical reaction to produce biodiesel is as follows:

$$\text{Oil (vegetable tri-ester)} + \text{Alcohol (methanol)} \xrightarrow{\text{catalyst}} \text{Alkyl esters (biodiesel)} + \text{Glycerin (component of soap)}$$

(R represents a hydrocarbon chain that is highly variable in length: 14-24 carbon atoms)

Materials:

- lab balance (if using NaOH or KOH base in solid form)
- 2 × 250 mL Erlenmeyer flasks and stoppers
- 100 mL graduated cylinder
- 50 mL graduated cylinder
- disposable pipettes or a turkey baster
- thermometer
- warm water bath (40–60 °C)
- 100 mL oil (a different oil for each group is best; possible oils are canola, olive, safflower, lard (warmed to liquid), strained deep fryer oil, grape seed, flaxseed, and sesame. **Avoid nut oils because of potential allergies.**)
- 20 mL methanol
  
  **Cautionary note:** Flammable, dangerous fire risk, toxic by ingestion
- ONE of the following base solutions or solid base crystals: 15 mL of 1.0 mol/L NaOH(aq), 15 mL of 1.0 mol/L KOH(aq), 0.6 g of NaOH(s), 0.9 g of KOH(s)
  
  **Cautionary note:** NaOH and KOH solutions and solids are corrosive
- Safety goggles, gloves, and aprons

Safety:

- You must wear goggles, gloves, and an apron.
- Methanol is flammable and poisonous. Dispose of excess methanol by allowing it to evaporate in a fume hood, or as directed by your teacher.
- The finished product should be stored in a sealed container and away from heat sources.
Procedure:

Note: Biodiesel is made using three main components: oil, alcohol, and a base catalyst. This procedure provides a variety of alternative materials that you could use to produce the biodiesel. Your teacher will direct you to which materials you will be using.

Making Biodiesel:

1. Measure out 100 mL of oil using a graduated cylinder, and pour the oil into one of the Erlenmeyer flasks.

2. Record observations of colour, viscosity, clarity, and other aspects of the appearance of the starting material (oil).

3. Check that the temperature of the water bath is between 40 °C and 65 °C. Place the Erlenmeyer flask containing the oil sample into a water bath set up by your teacher.

4. While your oil is warming, measure out 20 mL of methanol using a 50 mL graduated cylinder and pour it into a second Erlenmeyer flask.

5. To the Erlenmeyer flask containing the methanol, add ONE of the following: 15 mL of 1.0 mol/L NaOH(aq) solution, 15 mL of KOH(aq) solution, 0.6 g of NaOH(s), or 0.9 g of KOH(s). Swirl your mixture of methanol and base gently to mix. This mixture is called methoxide.
   • If using a solid base, the mixture should be swirled or stirred until the solid base dissolves completely.
   • To prevent evaporation, this mixture should be stoppered until it is ready to be added to the oil.

6. Pour the methoxide mixture into the warm oil in the Erlenmeyer flask.

7. Stir, swirl, or stopper and gently shake the mixture for several minutes. The mixture will become cloudy and turn a milky colour. A stopper or aluminum foil can be used on the flask to control fumes.

8. If the reaction is successful, you should start seeing two layers developing inside the flask. The heavier glycerin will start to settle to the bottom soon after you stop mixing the reactants. The biodiesel will be in the upper layer. The biodiesel varies in colour depending on the oil used. This will take at least an hour, but longer is better. The mixture should sit overnight to completely react.
Collecting Biodiesel (Best completed the next day):

9. Use a disposable pipette or a turkey baster to carefully remove the top layer, containing the biodiesel, from the Erlenmeyer flask and move it to a clean graduated cylinder.

10. Record the volume of the biodiesel transferred from the Erlenmeyer flask in Table 1 on page 6.

11. Record observations of colour, viscosity, clarity, and other aspects of the appearance of the starting material (oil) and the product (biodiesel) collected in Table 2 on page 6.

12. Place the biodiesel into an appropriately labelled container. Ensure that the contents of the container are identified, and add an appropriate WHMIS label, your name, and today’s date.

Note: This is crude biodiesel and is NOT of a high enough quality to put directly into a vehicle. In industrial processes, it must go through a process called “washing” to remove excess glycerin, base, and alcohol.
Burning the Biodiesel (Your teacher may demonstrate this step):

13. Biodiesel can be safely used in spirit burners. Pour some of your biodiesel into a spirit burner. Once the biodiesel has soaked up the wick, light the wick of the spirit burner. If the biodiesel does not soak up the wick, use the pipette to place a few drops on the wick. Record your observations in Table 3 on page 6.

14. Try burning the unreacted oil and the methanol in other spirit burners. For each different fuel tested, record your observations in Table 3 on page 6.

15. Store the remainder of the biodiesel in an appropriate container labelled with your name. This may be used for Extension A of this project.
Data and Observations:

Table 1: Quantitative Observations of Reaction

<table>
<thead>
<tr>
<th>Volume of oil (mL)</th>
<th>Volume of biodiesel (mL)</th>
<th>Percent yield of the reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Starting Reactant</strong></td>
<td><strong>Product</strong></td>
<td><strong>% Yield = ( \frac{Product}{Reactant} \times 100 )</strong></td>
</tr>
</tbody>
</table>

Table 2: Qualitative Observations of Reaction

<table>
<thead>
<tr>
<th>Observations of Reactants (e.g., colour, smell, viscosity, etc.)</th>
<th>Observations of Products (e.g., colour, smell, viscosity, etc.)</th>
</tr>
</thead>
</table>

Table 3: Qualitative Observations for Burning of Fuels

<table>
<thead>
<tr>
<th>Type of Fuel in Burner</th>
<th>Colour of Flame</th>
<th>Description of Smoke Produced</th>
<th>Smell</th>
<th>Other Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biodiesel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unreacted vegetable oil or animal fat</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanol</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion and Evaluation:

1.1 Use the data from tables 2 and 3 on page 6 to qualitatively compare the products (biodiesel and glycerin) with the starting reactants (methanol and oil).

......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................

1.2 Evaluate the yield of biodiesel produced in the experiment. In commercial production of biodiesel, yields are often around 80% biodiesel. How does your yield compare to the commercial yield? If you used different types of oils, how did the yields of the different oils compare?

......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................

1.3 Calculate the cost to make 300 L of biodiesel using the following information.

i. Methanol costs about $0.85/L and you need 0.2 L for every litre of biodiesel.

ii. Lye (NaOH or KOH) can be bought at a hardware store for about $7/kg, and you will need about 1.4 kg for 300 L of oil.

iii. Assume you can obtain waste oil for free from a local restaurant.
1.4 Compare the cost of making biodiesel ($/L) with the cost of purchasing regular diesel and/or gasoline at the pump ($/L) at current prices.

......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................

1.5 Suggest modifications to the procedure and design of the experiment that would either increase the amount of product from the process or improve the success of testing the product.

......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................


<table>
<thead>
<tr>
<th>Score</th>
<th>Scoring Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>4 Standard of Excellence&lt;br&gt;The experiment is completed efficiently, with little or no extra guidance required. Detailed observations are made. Explicit references to data collected are made when conclusions are drawn and modifications are described.</td>
</tr>
<tr>
<td>3</td>
<td>3&lt;br&gt;The experiment is completed with some extra guidance required. Correct observations and conclusions are made, and references to the data collected are made when conclusions are drawn and modifications are described.</td>
</tr>
<tr>
<td>2</td>
<td>2 Acceptable Standard&lt;br&gt;The experiment is completed in a manner that enables the collection of reasonably accurate data. Correct observations and reasonable conclusions are made. Limited reference to the data collected is made when conclusions are drawn and modifications are described.</td>
</tr>
<tr>
<td>1</td>
<td>1&lt;br&gt;The experiment is completed using techniques that enable the collection of only limited and incomplete data. Incorrect observations and conclusions are made, and vague references to data collected are made.</td>
</tr>
<tr>
<td>0</td>
<td>0&lt;br&gt;The performance is not at an appropriate level for a 30-level course.</td>
</tr>
</tbody>
</table>
Part 2: The Chemistry of Making Biodiesel

Use the following unbalanced chemical equation to answer the next four questions.

Biodiesel Reaction

\[
\text{Oil (vegetable tri-ester)} \quad + \quad \text{Alcohol (methanol)} \quad \xrightarrow{\text{catalyst}} \quad \text{Alkyl esters (biodiesel)} \quad + \quad \text{Glycerin (component of soap)}
\]

Pre-Activity Questions:

2.1 **Identify** the functional group found in the vegetable oil molecule. Circle it in the equation.

.......................................................................................................................................

2.2 **State** the name of the alcohol mixed with the vegetable oil in this reaction, and **list** some of the properties of this alcohol or alcohols in general.

.......................................................................................................................................

.......................................................................................................................................

.....................................................................................................................................

2.3 **Explain** what the “R” represents in the biodiesel chemical structure.

.......................................................................................................................................

Activity:

Using molecular model kits, marshmallows and toothpicks, or other materials, build a model that represents the reaction shown above. Your model should demonstrate the following aspects of a chemical reaction:

• stoichiometric relationships (correct balancing of amount of substances, or each type of atom, involved in the process)
• differences in the chemical structures between reactants and products.

**Note:** Use a single object in your model to represent “R.”
2.4 State the similarities and differences between the saponification reaction shown above and the chemical reaction that produces biodiesel depicted in your model.

Use the following unbalanced chemical equation to answer the next question.

Saponification (Soap-Making) Reaction

\[
\begin{align*}
\text{O} & \quad \text{O} \\
\text{CH}_2\text{O} & \quad \text{C(CH}_2\text{)}_{14}\text{CH}_3 \\
\text{CH} & \quad \text{CH} \\
\text{CH}_2\text{O} & \quad \text{C(CH}_2\text{)}_{14}\text{CH}_3 \\
\text{An oil} & \quad \text{Glycerin} \\
\hline
\end{align*}
\]

\[3 \text{ NaOH} \quad \text{(or KOH, potassium hydroxide)} \rightarrow \begin{align*}
\text{CH}_2\text{OH} \\
\text{CH}_2\text{OH} \\
3 \text{CH}_3\text{(CH}_2\text{)}_{14}\text{CO}_2\text{Na}
\end{align*}\]


<table>
<thead>
<tr>
<th>Score</th>
<th>Scoring Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>The response is <strong>well organized</strong> and addresses <strong>all</strong> the major points of the question using <strong>appropriate and clear</strong> communication strategies. The description of relevant scientific, technological, and/or societal concepts is <strong>explicit</strong>. Descriptions and/or explanations of the interrelationships between the concepts are <strong>correct</strong> and <strong>reflect a thorough understanding</strong> of the question.</td>
</tr>
<tr>
<td>3</td>
<td>The response is <strong>organized</strong> and addresses the major points of the question using <strong>appropriate</strong> communication strategies. The description of relevant scientific, technological, and/or societal concepts is <strong>evident</strong>. Descriptions and/or explanations of the concepts are <strong>mostly correct</strong> and <strong>reflect a correct understanding</strong> of the question.</td>
</tr>
<tr>
<td>2</td>
<td>The response is <strong>generally organized</strong> and addresses <strong>most</strong> of the major points of the question using <strong>adequate</strong> communication strategies. Descriptions of relevant scientific, technological, and/or societal concepts are <strong>present</strong>. Descriptions of the concepts are <strong>generally correct</strong> and <strong>reflect an adequate understanding</strong> of the question.</td>
</tr>
<tr>
<td>1</td>
<td>The response is <strong>not well organized</strong> and addresses <strong>few</strong> of the major points of the question using inadequate communication strategies. Descriptions of relevant scientific, technological, and/or societal concepts are <strong>limited or not evident</strong>. Descriptions of the concepts are <strong>vague or lacking</strong> and <strong>reflect a poor understanding</strong> of the question.</td>
</tr>
<tr>
<td>0</td>
<td>The response does not address any of the major points of the question at an appropriate level for a 30-level course.</td>
</tr>
</tbody>
</table>
Part 3: Does Biodiesel Work in the Cold?

Diesel engines differ from combustion engines in that they are lubricated by the fuel combusted, not by oil added to the engine. A second difference is that a diesel engine starts and stops with fuel in the system. A challenge for the designers of diesel engines is the change in the properties of diesel fuel that occurs at lower temperatures: it becomes a thick and viscous gel. This property of diesel is of particular concern in Alberta where temperatures during winter can be extremely low.

The viscosity of liquids can easily be compared using a 100 mL burette and a stopwatch. By measuring the time required for 100 mL of your fuel to flow from the stopcock of the burette, you can determine the viscosity of fuels. Another means of determining viscosity, used commonly in the fuel industry, is to measure the fuel’s cloud point (the temperature at which small, solid crystals first appear as the fuel is cooled). Determining a fuel’s cloud point is important because gelled or crystallized fuel will prevent the proper operation of a diesel engine.

Analysis:

3.1 You are given the task of developing a diesel-fuel that must contain some biodiesel and that must be acceptable for use in Alberta. Describe an experiment you would perform in order to

- determine the proportion of biodiesel/petrochemical diesel that would be most acceptable for use in cold Alberta temperatures.
- state the manipulated, responding, and controlled variables for your experiment.
### Scoring Guide for Skills Part 3: Does Biodiesel Work in the Cold?

<table>
<thead>
<tr>
<th>Score</th>
<th>Scoring Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4 Standard of Excellence</strong></td>
<td>An appropriate and practical experimental design is presented. The design of the overall study is based on a thorough understanding of the principles of scientific inquiry.</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>An appropriate and somewhat practical experimental design is presented. The design of the overall study is based on a correct understanding of the principles of scientific inquiry.</td>
</tr>
<tr>
<td><strong>2 Acceptable Standard</strong></td>
<td>A generally appropriate or a practical procedure with some omissions or errors is presented. The design of the overall study is based on a generally correct understanding of the principles of scientific inquiry.</td>
</tr>
<tr>
<td><strong>1</strong></td>
<td>An incomplete or an impractical procedure with major omissions or errors is presented. The design of the overall study is based on a generally superficial understanding of the principles of scientific inquiry.</td>
</tr>
<tr>
<td><strong>0</strong></td>
<td>The response does not address any of the major points of the question at an appropriate level for a 30-level course.</td>
</tr>
</tbody>
</table>
Part 4: A Risk–Benefit Analysis

Our society is dependent on petroleum products for heat, electricity, and transportation. Unfortunately, petroleum is a limited and non-renewable resource. In addition, the supply of petroleum products is not always reliable, resulting in fluctuating fuel prices. Researchers are searching for ways to supplement and/or replace petroleum fuels, and consumers are looking for cheaper alternatives. Biodiesel is a fuel that has been proposed as either an alternative or as a means to supplement petroleum-diesel or gasoline.

Complete a risk–benefit analysis to answer the following question: Should the production and sale of biodiesel be promoted in Canada? Use the Internet and other text sources as well as information you collected, analyzed, and evaluated while doing this project to help you formulate your opinion.

In preparing your analysis, consider a variety of issues including the following: reliability, safety, economic impact, environmental impact, accessibility of the resource, production potential, long-term viability as a resource, and other relevant issues. Supporting statements should be provided for all opinions and evaluations made.

Present your risk–benefit analysis as a poster, PowerPoint presentation, or flowchart.

Scoring Guide for Part 4: Risk–Benefit Analysis

<table>
<thead>
<tr>
<th>Score</th>
<th>Scoring Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>The response is well organized and addresses all the major points of the question using appropriate and clear communication strategies. The interrelationships between science, technology, and society are thoroughly understood. Risks and benefits are thoroughly evaluated. Insufficient and convincing arguments are used to support a decision or judgment, and a range of viewpoints is considered.</td>
</tr>
<tr>
<td>3</td>
<td>The response is organized and addresses the major points of the question using appropriate communication strategies. The interrelationships between science, technology, and society are understood. Risks and benefits are evaluated. Clear and logical arguments are used to support a decision or judgment, and alternative viewpoints are considered.</td>
</tr>
<tr>
<td>2</td>
<td>The response is generally organized and addresses most of the major points of the question using adequate communication strategies. The interrelationships between science, technology, and society are generally understood. Risks and benefits are listed. Logical arguments are used to support a decision or judgment, and viewpoints are considered.</td>
</tr>
<tr>
<td>1</td>
<td>The response is not well organized and addresses few of the major points of the question using inadequate communication strategies. The interrelationships between science, technology, and society are poorly understood. Few risks and benefits are listed. Poorly formed arguments are used to support a decision or judgment, and viewpoints are sketchy or not provided.</td>
</tr>
<tr>
<td>0</td>
<td>The response does not address any of the major points of the question at an appropriate level for a 30-level course.</td>
</tr>
</tbody>
</table>
Extension: Determining the Energy Content of Biodiesel

Purpose:

In this section of the lab, you will use the formula \( Q = mc\Delta T \), listed on page 5 of the data booklet. Prepare a formatted spreadsheet that calculates the energy released by the vegetable oils used as reactant materials and compares it with the energy of the different biodiesel fuels produced by the process used in Part 1 of the project (Making Biodiesel).

Materials:

- 3, 25 × 200 mm test tubes
- distilled water
- vegetable oil (used as a reactant in Part 1)
- methanol (the alcohol used in Part 1)
- biodiesel (produced from vegetable oil in Part 1)
- 3 spirit burners
- test-tube clamp and stand
- thermometer and clamp
- safety goggles, gloves, and aprons
- 50 mL graduated cylinder
- matches

Procedure:

1. Use an electronic balance to measure the mass of three spirit burners containing the following three fuels: vegetable oil, methanol, and biodiesel (prepared in Part 1). Record the mass of each burner in Table 4 on page 6.
2. Use a graduated cylinder to measure 30.0 mL of distilled water, and transfer the water to a 25 × 200 mm test tube. Place the test tube in a test-tube clamp attached to a stand. (Note: Use the approximation that 1 mL of water has a mass of 1.0 g.)
3. Position the test tube so that the bottom of the test tube is 2 cm above the wick of the unreacted spirit burner containing the vegetable oil.
4. Use a thermometer to measure the initial temperature of water inside the test tube. Record the initial temperature of the water in Table 4 on page 6.
5. Light the wick of the spirit burner and use the flame to heat the bottom of the test tube for 60 seconds.
6. Remove the spirit burner from underneath the test tube, and use the burner lid to extinguish the flame.
7. Use the thermometer to measure the final temperature of the water. Record the temperature in Table 4 on page 6.
8. Measure the mass of the spirit burner, and record the value in Table 4 on page 6.
9. Repeat steps 2 through 8 using a new test tube with water and the spirit burner containing the alcohol.
10. Repeat steps 2 through 8 using a new test tube with water and the spirit burner containing the biodiesel produced in Part 1 of the project.
Observation Table, and Analysis and Assessment:

Prepare a spreadsheet using the column headings shown below. Input the data collected from the experiment into the appropriate cells in the table. Add rows as necessary if other oils and biodiesels are tested.

Table 4: Data for Burning Fuels

<table>
<thead>
<tr>
<th>Type of Fuel Used in Burner</th>
<th>Mass of Water (g)</th>
<th>Specific Heat Capacity of Water (J/g°C)</th>
<th>Initial Temperature of Water (°C)</th>
<th>Final Temperature of Water (°C)</th>
<th>Mass of Spirit Burner and Contents Before Combustion (g)</th>
<th>Mass of Spirit Burner and Contents After Combustion (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.19</td>
<td>4.19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Use the formula $Q = mc\Delta T$ to calculate the energy absorbed by the water in 1 minute.

1. Add the following four columns to your spreadsheet:
   - Mass of Fuel Burned (g)
   - Temperature Change of Water (°C)
   - Energy Released by Fuel in One Minute (J)
   - Energy Released per Gram of Fuel Burned (J/g)

2. Select the cell in the first row of data under the heading “Mass of Fuel Burned (g).”

3. Identify the appropriate values that appear in the first row of data, and construct a formula that enables the spreadsheet to calculate the mass of fuel that was burned in the first spirit burner during the experiment.

4. Repeat the process using appropriate values from the second row of the data table to have the spreadsheet calculate the mass of the fuel burned in the second spirit burner.

5. Repeat as above using the data for the third burner.

6. Repeat step 2 to have the spreadsheet calculate values to appear in the following columns: Temperature Change of Water (°C), Energy Released by Fuel in One Minute (J), and Energy Released per Gram of Fuel Burned (J/g).
Evaluation:

E.1 Compare the quantities of energy released during the combustion of the vegetable oil, the methanol, and the biodiesel.

......................................................................................................................................
......................................................................................................................................
......................................................................................................................................

E.2 Methanol contains a lot of chemical energy. Why not use methanol as a fuel instead of being used to make biodiesel?

......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................

E.3 Compare your results with the results of your classmates. Identify how the biodiesels produced from different vegetable oils differ with respect to the quantity of energy released when they are combusted. State which of the biodiesels tested would make the best fuel.

......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
......................................................................................................................................
## Scoring Guide for Extension:
Determining the Energy Content of Biodiesel

### Practical Skills

<table>
<thead>
<tr>
<th>Score</th>
<th>Scoring Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4</strong> Standard of Excellence</td>
<td>The experiment is completed efficiently, with little or no extra guidance required. Detailed observations are made. Explicit references to data collected are made when conclusions are drawn and modifications are described.</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>The experiment is completed with some extra guidance required. Correct observations and conclusions are made, and references to the data collected are made when conclusions are drawn and modifications are described.</td>
</tr>
<tr>
<td><strong>2</strong> Acceptable Standard</td>
<td>The experiment is completed in a manner that enables the collection of reasonably accurate data. Correct observations and reasonable conclusions are made. Limited reference to the data collected is made, when conclusions are drawn and modifications are described.</td>
</tr>
<tr>
<td><strong>1</strong></td>
<td>The experiment is completed using techniques that enable the collection of only limited and incomplete data. Incorrect observations and conclusions are made, and vague references to data collected are made.</td>
</tr>
<tr>
<td><strong>0</strong></td>
<td>The performance is not at an appropriate level for a 30-level course.</td>
</tr>
</tbody>
</table>

### Analysis of Data

<table>
<thead>
<tr>
<th>Score</th>
<th>Scoring Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4</strong> Standard of Excellence</td>
<td>All required data are accurately manipulated using a spreadsheet. Accurate interpretations and conclusions are made, based on an analysis of the data. Insightful and convincing arguments are used to support a decision or judgment.</td>
</tr>
<tr>
<td><strong>3</strong></td>
<td>The majority of data are accurately manipulated using a spreadsheet. Interpretations and conclusions are made, based on an analysis that is consistent with the data. Clear and logical arguments are used to support a decision or judgment.</td>
</tr>
<tr>
<td><strong>2</strong> Acceptable Standard</td>
<td>A reasonable portion of the data is accurately manipulated using a spreadsheet. The data are partially analyzed. Interpretations and conclusions are generally based on an analysis of the data. Logical arguments are used to support a decision or judgment.</td>
</tr>
<tr>
<td><strong>1</strong></td>
<td>The data are incorrectly analyzed using a spreadsheet. Interpretations and conclusions are incorrect or are not based on an analysis of the data. Poorly formed arguments are used to support a decision or judgment.</td>
</tr>
<tr>
<td><strong>0</strong></td>
<td>The response does not address any of the major points of the question at an appropriate level for a 30-level course.</td>
</tr>
</tbody>
</table>