Soybean Oil: Powering A High School Investigation of Biodiesel

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Student Handouts

Objective: Students will investigate the science and sustainability of biodiesel and current criteria governing commercially sold fuels according to the U.S. Energy Independence and Security Act of 2007. In this lab, biodiesel (an alternative fuel) will be synthesized from soybean oil and blended with Diesel No. 2 to power an engine. This investigation will review bonding in organic compounds, energy content values of various fuels, and alternative fuel technologies within the perspective of sustainable development and environment stewardship.

Educational Relevance: Molecules are compounds that contain covalent bonds in which nonmetal atoms share valence electrons. These bonds can consist of single, double, and/or triple bonds. During chemical reactions, bonds are breaking and forming, which either require or produce energy. One reaction in particular that produces energy is a combustion reaction. This reaction can heat a school on a cold day or propel an automobile as a form of transportation. The continued use of petroleum-based fuels is non-sustainable and scientists are currently developing alternative fuel sources.

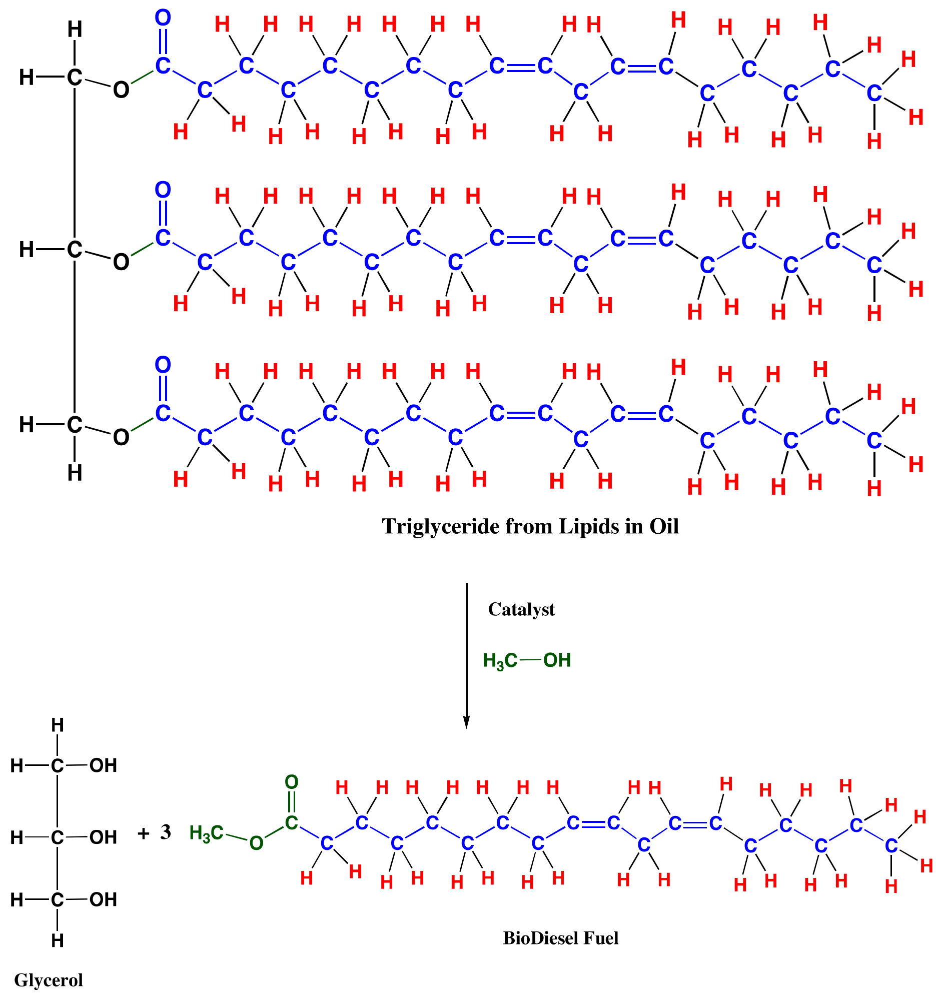
Background:

Petroleum Fuels:

As fuel is burned in a combustion engine, energy is produced that powers an automobile. Amongst the emissions produced during the reaction are carbon dioxide and water. Diesel No. 2 is a fuel that can be purchased from gas stations. Similar to gasoline, diesel is produced from crude fossils oil during the oil refinery process. Diesel is a 'heavy' oil that contains a chain of 12-20 carbons (average of 16 carbons) that are saturated with hydrogens. Petroleum fossil fuels are also known as hydrocarbons because they primarily contain carbon and hydrogen. However, crude oils also contain sulfur and nitrogen-containing compounds. The continued use of petroleum-based transportation fuels is non-sustainable and the emissions have been implicated in several issues of environmental pollution and global warming.

Approximately 94% of the U.S. transportation energy is supplied by petroleum-based fuel. The average American uses approximately three gallons of fuel per day, which equates to $250 billion/year nationally being spent on transportation fuel. This is an overwhelming concern since over the past 40 years, more than half of the oil used for transportation is now imported from foreign countries. The use of fuels that are produced from non-renewable resources is problematic because these reserves are dwindling as annual consumption needs continue to escalate. Scientists are faced with proposing innovative developments in fuel technology that meet the needs of the current market without compromising the ability of future generations to meet their own needs.

<u>Biodiesel</u>



Scheme 1: Transesterification of a triglyceride to a Fatty Acid Methyl Estser

Alternatively, biodiesel has fuel properties similar to petrodiesel and can be used directly in a diesel engine. Biodiesel is produced from the oils (triglycerides) of plants and animals. Triglycerides of seed oils such as soy, corn, and canola have similar structures. Triglycerides are fats that are composed of a glycerol and three fatty acid molecules. The chain lengths of the fatty acids in naturally occurring triglycerides can be of varying lengths but 16, 18, and 20 carbons are the most common. Naturally occurring fatty acids, found in plants and animals, are typically composed only of even numbers of carbon atoms due to the way they are synthesized. Collectively, the US has the ability to grow enough soybeans to meet both food demands and address the need for an alternative energy sources, such as biodiesel.

Using chemistry, in this challenge, triglycerides of soybean oil can be converted to biodiesel that can power diesel engines in tractors, trucks, planes, and even trains. This is possible because the carbons chain lengths of biodiesel (16-20 carbons) are similar to that of regular diesel fuel (12-20 carbons). Biodiesel is a methyl ester of the free fatty acids of a triglyceride or FAMEs (Free Fatty Acid Methyl Esters). [Scheme 1]

Diesel Engines and Emissions

The idea of using vegetable oil as a fuel source is almost as old as the internal combustion engine itself. Rudolf Diesel presented the invention of a Diesel engine at the 1900 World's Fair in Paris. This engine ran exclusively on peanut oil. The diesel engine was eventually marketed to farmers who could grow their own fuel to power the engine. Later, in 1912, Rudolf Diesel commented to the Institution of Mechanical Engineers (of Great Britain): "One cannot predict what part these oils will play in the Colonies of the future. In any case, they make it certain that motor-power can still be produced from the heat of the sun, which is always available for agricultural purposes, even when all our natural stores of solid and liquid fuels are exhausted."

Biodiesel is a cleaner burning alternative to diesel. This is because triglycerides lack nitrogen and sulfur atoms that are often found in fossils that produce crude oil. Following combustion, the nitrogen atoms bind with oxygen to make nitrogen oxides (NO_x). These nitrates lead to surface-level smog that affects the quality of the air that is inhaled. When sulfur is emitted as diesel is burned in an engine, the sulfur atoms bind with oxygen atoms to make sulfates (SO_x) that can lead to acid rain. The use of biodiesel virtually eliminates these particular harmful emissions. Diesel engines can be powered with 100% biodiesel (B100) or even a mixture of biodiesel and diesel. [B80 = (A fuel mixture containing 80% biodiesel and 20% diesel) B20 = (A fuel mixture containing 20% biodiesel and 80% diesel)] The US Navy uses B20 in all non-tactical vehicles and is the largest user of biodiesel in the world. Additionally, many local campuses and companies that have large fleets of vehicles have limited their petroleum consumption by utilizing B20 as an alternative fuel. Most importantly, even a small amount of biodiesel in the blend of fuel with diesel reduces the harmful emissions up to 50% in some cases. This causes the engines to burn cleaner sustainable fuels and even extends the lifetime of the engine due to the superior lubrication of biodiesel compared with diesel.

Student Tasks: Each lab group is to develop an experimental protocol to address the following questions to produce an alternative fuel that meets the US Energy Independence and Security Act of 2007.

- Research an experimental procedure to convert soybean oil to biodiesel from a reputable website or a science journal article.
- Plan how you will separate biodiesel from the byproducts formed during the reaction.
- Design multiple experiments to determine how much energy is contained in a sample of B100.
- Investigate how different is the energy content of B100 compared to B20 or Diesel No. 2.
- Develop criteria to evaluate if an alternative fuel can meet the needs of the next generation?

Procedure

<u>Biodiesel Synthesis</u>

Supplies:

- Soybean Oil
- Methanol
- Potassium carbonate
- 1 M acetic acid
- Scale
- Round-bottom flask (100-500 mL)
- Reflux condenser
- Boiling chips
- Ring stands
- Scoopula
- O-ring support
- Clamps
- Bunsen burner
- Separatory funnel
- Waste beaker

Student Procedure:

1. Put on your safety glasses and personal protective gear.
2. Pre-assemble a reflux condenser that is attached with water inlet tubes.
3. Weigh 20.00 grams of soybean seed oil into a round bottom flask and add 3-4 boiling chips.
4. Add 5.58 mL of methanol and 1.2 grams of potassium carbonate to the round-bottom flask. Secure the setup to a ring stand that is supported using an O-ring clamp.
5. Grease and attach a reflux condenser to the round bottom flask and support the condenser to the ring stand with a clamp.
6. Turn on the cold water and place a Bunsen burner under the round-bottom flask and gently heat the system to reflux.
7. Once the system reaches reflux continue heating for 25 minutes (Be sure to keep the flame at a low intensity).
8. After heating for 25 minutes allow the system to cool.
9. Remove the condenser and add 17.5 mL of 1 M acetic acid to the flask to neutralize the catalyst.
10. Move the reaction mixture to a separatory funnel that is clamped and supported to a ring stand.
11. Allow the layers of the reaction mixture to separate.
12. Clean all glassware/supplies and record your observations.

Fuel Blending and Energy Density

Supplies:

- Biodiesel (B100)
- Diesel No. 2 Fuel
- Graduated cylinders (50 mL, and 10 mL)
- Fuel lamps with cotton wicks (3 per group)
- Storage vials
- Matches
- Stopwatch (1 per group)

1. Put on your safety glasses and personal protective gear.
2. Drain the lower glycerol layer into a waste beaker and collect the upper layer containing biodiesel into a tarred beaker or vial labeled with your group name.
3. Record the mass of collected biodiesel in your notebook.

Fuel Blending

4. Make a 40 mL solution of your Diesel No. 2 and your biodiesel fuel in an 80:20 mixture by measuring 32 mL of Diesel No. 2 and 8 mL of biodiesel in graduated cylinders and mixing the two in a clean vial. Mix several times by inverting the capped vial.

Energy Density (Amount of stored energy in a given unit volume)

1. To three separate fuel lamps, add 5 mL of B100, B20, and Diesel No. 2 and make sure the cotton wick is submerged in the fuel.
2. Light the lamp using a match and record how long each lamp burns using a stopwatch. When the flame is extinguished record the time in your lab notebook.

Heat Value Analysis
Supplies:
- Scale
- Graduated cylinder
- Glass stir rod or pencil
- O-ring support
- Clamps
- Thermometer
- Ring stand
- Small beaker
- Fuel holder (Cork cap, paper clip) [2 per group]
- Cotton balls (at least 6 per group)
- Pipette dropper
- Empty soda cans (4 per group)
- Waste beaker

Heat Value (Energy released as heat when a fuel undergo combustion)
1. Put on your safety glasses and personal protective gear.
2. Using a graduated cylinder measure 50 mL of tap water. Pour the water into an empty, clean, aluminum soda can.
3. Each group should set up two calorimeters. Put a glass-stirring rod (or pencil) through the pull-tab of the can from the previous step. Rest the ends of the rod on the ring of a ring stand to suspend the can by the tab from the ring.
4. Measure and record the initial temperature of the water. The thermometer should not touch the bottom of the can.
5. Measure and record the mass of a nonflammable holder with a cotton ball attached to the top of the holder.
6. Add 50 drop of each fuel (B100, B20, and Diesel No. 2) to three separate cotton balls.
7. Record the mass of the holder and the cotton ball carrying 50 drops of the fuel.
8. Place the fuel sample with its holder under the can. Adjust the height of the can so the sample is approximately 4 inches from the bottom of the suspended can.
9. Remove the sample and holder from underneath the can and light it with a match. Once the sample begins to burn, reposition the holder underneath the can. If the sample stops burning before it is completely charred, pull the sample and holder out from under the can, relight the sample, and reposition the burning sample and holder back under the can.
10. Use a thermometer to stir the water gently as the fuel burns. Record the highest temperature reached by the water. (The thermometer should not touch the bottom of the can.)
11. After the sample is completely burned, allow the system to cool. Empty the water from the can, and wash and dry the outside.
12. Repeat steps 2-11 using the next fuel sample. Each group should conduct 2 trials simultaneously.
13. Clean all glassware/supplies and record your observations.

Data Analysis of Heat Value

Student Procedure:

1. Solve this problem: What is the heat in Joules required to raise the temperature of 25 grams of water from 0 °C to 100 °C? [Useful information: $q_v = C \times dT \times m$ where q_v is heat, C is specific heat capacity of water (4.18 J/g·°C), dT is change in temperature, and m is the mass of water.]

2. Convert the heat value in exercise #1 to calories. (Useful information 4.18 J = 1 calorie)

3. Calculate the energy and calories from each fuel (B100, B20, and Diesel No. 2) used to heat the water in a given trial.

Sample	Mass of Fuel	Change in Temperature	Heat Value q_v (in Joules)	Calories (cal)	Calories per gram of fuel
Trial 1 B100					
Trial 2 B100					
Trial 1 B20					
Trial 2 B20					
Trial 1 Diesel No. 2					
Trial 2 Diesel No. 2					

Student Pre-laboratory Exercises

Name __________________________ I.D. _________________________

Period ________ Instructor ______________________

1. There are two types of fuels – gasoline and diesel. Describe the differences between these fuels. Where do they come from and how are they chemically different?

2. What are some alternatives to using petroleum as a fuel source?

3. Can you describe the oil refinery process and how many types of fuels products are produced from crude oil?

4. Use the Internet and write a detailed procedure to synthesize biodiesel from any type of oil.

5. What are the products from the transesterification of triglycerides and methanol?

6. Describe characteristics of a fatty acid. Draw oleic acid showing all bonds.

7. There are nutritional labels on many food packages that inform consumers of how many calories are in a serving of a product. Describe how this number is calculated?

8. How many milliliters of 1 M acetic acid are required to neutralize a reaction containing 1.2 g of K_2CO_3?

Student Post-laboratory Exercises:

Name ________________________ I.D. ________________________
Period _______ Instructor ____________________

1. Chemically define biodiesel.

2. What would be the economic impact on global resources if biodiesel were implemented as an alternative fuel?

3. Could the by-products produced during the synthesis of biodiesel be further used to make a developing alternative fuel economy more profitable?

4. How is biodiesel a cleaner burning fuel compared to petrodiesel and what impact does it make on global emissions?

5. How can scientists further test the quality of biodiesel beyond what was performed in this lab experiment?

6. How can biodiesel from land-based sources (like soybeans) be used to make fuel that will not affect the global supply of food?

7. How does the energy density and heat value of B100 and B20 produced by your lab group compare to Diesel No. 2?

8. If 1.48 g of B100 raises the temperature of a 50.0 g sample of water from 14.4 ˚C to 37.7 ˚C, calculate the energy (in Joules) and calories per gram contained in this fuel sample. (Show your work)

Student Lab Notebook (Biodiesel Synthesis) **Name: ________________**

Objective (Rewrite the objective of this lab in your own words)**:**

Procedure (Rewrite the biodiesel synthesis procedure in your own words)**:**

<u>Biodiesel Synthesis Data:</u>

Mass of soybean oil used: __________

Describe the appearance of the biodiesel compared to the soybean oil:

Volume of methanol used: __________

Mass of potassium carbonated used: __________

Moles of potassium carbonated used: __________

Moles of acetic acid required to neutralize the reaction: __________

Volume of 1 M acetic acid required to neutralize the reaction: __________

Describe the appearance of the reaction once the acetic acid is added:

Mass of collected biodiesel: __________

Describe the appearance of the biodiesel compared to the soybean oil:

Student Lab Notebook (Energy Analysis) **Name: ________________**

Procedure (Rewrite the energy density and heat value analysis procedures in your own words)**:**

Energy Density:

Record the time that each fuel burned in the fuel lamp

Sample	Burn Time (in min.)
B100	
B20	
Diesel No. 2	

Heat Value:

Sample	Average Mass of Fuel	Average Change in Temperature	Average Heat Value q_v (in Joules)	Average Calories (cal)	Average Calories per gram
B100					
B20					
Diesel No. 2					

Compare the heat value and energy density of each fuel. Are B100 and B20 viable alternative fuels that display similar energy content values compared to Diesel No. 2?

Describe global concerns that may arise from utilizing a plant-based fuel source as an alternative to petroleum fuels.

Teacher Notes

Guided-Inquiry: The authors would like to note that this lab can be revamped to make it an guided-inquiry experiment by only providing the students with the first three pages of the Student Handouts. The students can be given the opportunity to map the procedure and determine which pieces of data need to be collected throughout the experiment. The class procedure can be discussed after the individual student groups have developed a majority of the experimental methods. Once the procedure has been mapped, the students can then use the outline to lead them in determining what data needs to be collected in the experiment.

Scaffold Procedure: If the teacher desires to run the lab using more scaffolding, the procedure and pieces of data that should be collected can simply be provided to the students as in the Student Handout.

In this experiment, students will synthesize biodiesel from soybean oil using methanol and an alkaline catalyst. Following the synthesis, the reaction can be neutralized and the products separated. The students will analyze the alternative fuel by calculating the heat value and energy density of the alternative fuels during a calorimetric analysis and timed combustion of the fuel.

Educational Relevance: This experiment should be run as the students are discussing bonding in organic molecules. The bonding in triglycerides and petroleum hydrocarbons will be an ideal topic to revisit chemical reactions in which bonds are formed and broken in addition to colligative properties of the various products. Instructors should scaffold this introduction by revisiting calculations from solution molarity, titration calculations, and thermodynamic heat calculations utilizing specific heat and changes in temperature of a sample of water. This prior experience will allow the students to apply these principles to the analysis of an alternative fuel that adheres to the criteria within the US Energy Independence and Security Act of 2007, while personalizing the principles of sustainability and environmental stewardship.

Equipment Requirements: Equipment that could influence a successful implementation of this lab in a high school classroom could include limited access to reflux condensers and separatory funnels normally found in organic chemistry glass sets. Fortunately, a semi quantitative device reported by S. Logan (*J. Chem. Educ.* **2012**, *89*, 1609–1610) virtually eliminates the need for separatory funnels. Interestingly, the use of reflux condensers and distillations apparatus by high school teachers recently appeared in a JCE blog. Furthermore, instructors requiring additional support in the assembling or the use of reflux and distillation apparatus can review information in the following interactive tutorials that contain instructions, diagrams, and embedded videos.

"The Power of Seeing Chemistry in Action" by Lowell Thompson: http://www.jce.divched.org/blog/power-seeing-chemistry-action (accessed April 2014)

Royal Society of Chemistry "The Interactive Lab Primer: A Visual Guide to Common Laboratory Techniques (Simple Reflux)": http://chem-ilp.net/labTechniques/SimpleRefluxVideo.htm (accessed April 2014)

"Introduction to Distillation Apparatus" by Dr. Laurie Starkey: https://connect.csupomona.edu/distillation (accessed April 2014)

Procedural Modifications: a.) Instructors could convert the pre-lesson engagement regarding fuel technology to a student-centered exploration by having students present the pros/cons and similarities of various alternative fuels to petroleum sources; b.) Students could develop a synthetic protocol based off of individual research and inquiry-based discovery; c.) The acquisition of seed oils could be highlighted by requiring students to extract triglycerides from a natural product source, or the use of waste vegetable oils as the starting materials; d.) The environmentally safe disposal of the products and waste could be discussed with the students to further enhance their understanding of the environmental impact of any synthetic protocol.

Hazards and Waste Disposal

Potassium carbonate is an irritant and should be handled while wearing gloves and safety glasses. Exposure to skin by methanol, glacial acetic acid, soybean oil or the resulting Biodiesel should be flushed with water and washed with soap. Both the soybean oil and Biodiesel are combustible liquids with a closed cup flash point of approximately 282 °C. Diesel No. 2 is a flammable liquid with a closed cup flash point of 38 °C. The waste generated in this experiment could be separated and disposed as aqueous and organic waste streams. The aqueous waste should be neutralized and the organic waste should be disposed following typical laboratory protocols. Individual high school sites should also adhere to specific site, district, and state protocols. Some general guidelines regarding non-commercial Biodiesel waste procedures are available from the Environmental Protection Agency.

U.S. Environmental Protection Agency, Non-commercial and Home Biodiesel Waste: http://www.epa.gov/region7/biofuels/noncombiodiesel/waste.htm (accessed April 2014)

Pre-lab Discussion

The following questions served to a. quickly engage students in intellectual discourse, b.) introduce sustainability, environment stewardship and the topic of alternative fuel, and c.) prime the students to accomplish the laboratory task of the day.

Focus Questions (Pre-Lab Discussion):

- What are the criteria for a scientist to be awarded the Noble Prize?
- Dr. Richard Smalley, during his Noble Laureate tour, asked his colleagues to contribute to a list of the top ten issues facing humanity over the next fifty years. What do you think this list included?
- Just before many of you were born, in 1987 the UN Brundtland Commission defined Sustainability. What would be your definition of Sustainability?

- During *A Decade of Education for Sustainable Development (2005-2014)* many advances have been made. A recent piece of legislation known as the US Energy Independence and Security Act of 2007 defined criteria for alternative fuels to address the issue of sustainable energy. What are some alternative fuels you have heard of?
- What are some alternative fuels that can be used in combustion engines?
- What is the source of petroleum fuels and how are they purified and processed?
- Is the reliance on petroleum fuels sustainable?
- Please research a procedure for synthesizing this fuel from any seed, algae, or waste vegetable oils and complete the pre-lab questions prior to our first day of experimentation?

Biodiesel Synthesis

Focus Questions:

- What similarities did various group members find as they each researched known biodiesel syntheses? Are there any common reagents, reaction temperatures, reaction times, and procedures you all found in common?
- What is the definition of a chemical reaction?
- What is the role of methanol in this reaction?
- What is the definition of a catalyst?
- What is the role of the catalyst in this transesterification reaction?

The following instructor notes apply to the first day of experimentation:

- Have students work in group of 3-4 students
- Demonstrate to the class how to assemble a reflux condenser apparatus that includes a round-bottom flask, a reflux condenser, cold-water inlet tubes, clamps, and a ring stand. Then instruct the students to begin assembling their apparatus and adding the reagents to the flask.
- If digital scales are not available in the classroom, the instructor (or teacher's aid) may need to pre-weigh the catalyst to prevent elongated wait times associated with using a balance.
- Prior to allowing the student to light their Bunsen burners be sure the instructor checks the stability and height of the apparatus because adjustments to hot glassware could be hazardous.
- Be sure the round-bottom flasks are at least 2-3 inches above a low intensity flame to ensure the system is only gently refluxing.
- Remind students that their 25-minute reaction time should begin once their reaction is refluxing.

Separation of Biodiesel and Aqueous Layers:

- While neutralizing the reaction with acetic acid, a portion of students may have a soap emulsion form in the separatory funnel depending on the exact ratio of methanol and catalyst used in the reaction. If the funnels are allowed to sit undisturbed overnight, all the emulsions cleared allowing the student groups to easily separate their layers the following lab period.

- The biodiesel should be stored in glass vials or small beakers overnight if separated during the experiment. The fuel was able to decompose low-density polyethylene vials.

Fuel Blending and Energy Density

Focus Questions:

- Can anyone define what is the energy density of a fuel?
- When we eat food, nutritionists recommend we monitor the number of calories we are ingesting. What do calories represent?
- Can anyone describe how calories in a food source are determined?
- Using the available supplies, can each group design a modified version of a calorimetric experiment to determine the energy contained in samples of B100, B20, and Diesel No. 2?

The following instructor notes apply to the second day of experimentation:

- After separating the biodiesel and aqueous layers, the students should record the mass of their B100 fuel.

Fuel Blending

- The students should use approximately half of their B100 to make a B20 blend with Diesel No. 2. At least 9 mL of both B100 and B20 are required for energy analysis during the laboratory analysis. Excess B100 and B20 student samples should be collected to power the diesel engine using the various alternative fuels.

Energy Density

- 5 mL of each fuel B100, B20, and Diesel No. 2 should be added to a fuel lamp with a removable cap so the lamps can be reused in multiple class sections.
- The students should ensure the bottom of the cotton wick in the fuel lamp is submerged in the fuel and a portion is extending from the lamp to be burned. If the wick becomes too short it should be replaced to allow for consistent results. Each fuel lamp should be lit (as close to simultaneously as possible) and a stopwatch in each group started.
- A student in each group should be placed in charge to ensure the time when the flame is extinguished is recorded. The lamp is considered extinguished when a glowing amber is no longer visible and a stream of white smoke is being emitted from the wick (as if a candle has been blown out).
- Prior to allowing the student to light their heat lamps, be sure the instructor reviews safety protocols of proper procedures for working around an open flame.
- If time permits, students can begin reviewing the exercise to calculate the number of Joules (or calories) to raise the temperature of water by 100 ˚C listed in the student procedure in preparation for the heat value experiment on the following day.

Heat Value Determination

The following notes apply to the third day of laboratory activities:

Heat Value

- Have each group of students bring four 12-ounce soda cans to school for this experiment.
- Ensure the thermometers are in good working conditions and display temperature in degrees Celsius.
- Once the cotton balls containing fuel are lit, the flames produced are about 4 inches in height. Be sure the students assemble the cans at least this high above the cotton ball before lighting the fuel. Students should not attempt to adjust the apparatus while the fuel is being burned to avoid contacting hot lab equipment. If necessary, the fuel holder can be removed from under the can and extinguished if an unsafe situation develops.
- Commercially sold soda cans contain a plastic coating that will begin to blacken during the heating process throughout the experiment. This is minimized if the can height is increased above the cotton ball. Cans should only be used about two times as the soot of the can increases. Students should then switch to using a new can for the remainder of the experiments.
- This process can produce a considerable amount of smoke if a number of student groups are producing a flame that is decomposing the plastic coating on the outer portion of the aluminum cans. Ensure the room is well ventilated.

Data Analysis
The following notes apply to post-lab discussion activities:

1. Solve this problem: What is the heat in Joules required to raise the temperature of 25 grams of water from 0 °C to 100 °C?

   $q_v = C \times dT \times m$
   q_v = (25 g) x (4.18 J/g·°C) [(100 °C - 0 °C)]
   q_v = (25 g) x (4.18 J/g·°C) x (100 °C)
   q_v = 10450 J

2. Convert the heat value in exercise #1 to calories.

   4.18 J = 1 calorie
   x calories = 10450 J x (1 cal/4.18 J)
   x calories = 10450/4.18 calories
   x calories = 2500 calories

3. Calculate the energy and calories transferred to the water by burning each fuel (B100, B20, and Diesel No. 2).

- A similar set of calculations should be preformed to complete the required data for exercise #3. The final column (calories per gram of fuel) should be the calculated number of calories divided by the mass of the drops of fuel added to the cotton ball in each trial. This will allow the values from each group to be comparable despite the actual amount of fuel used in the individual trials.
- Each group should then average the values obtained in each trial and compare values as a class. These comparisons will allow for discourse regarding data precision and accuracy with respect to experimental error.

Powering a Diesel Engine

- At the completion of the data analysis, student samples that adhered to classroom quality assurance specifications were combined and used to power a diesel engine generator. (The fuel samples chosen to be combusted demonstrated consistency in the acquired energy density and heat values by the selected student groups.) The class can be allowed to vote to power the engine using an alternative fuel of their choice (B100 or B20). This will personalize the goal of this lab to produce an alternative fuel that adheres to the US Energy Independence and Security Act of 2007, and encourage the students to consider fuel advancements that are sustainable and have environmental benefits superior to petroleum fuel sources.
- Safety: Please exercise care when starting the engine. Students should remain a proper distance from the engine and be sure not to touch any moving parts (such as the shaft) or the exhaust pipe (which could be extremely hot).

Diesel Engine Modifications

- A Yanmar industrial diesel engine (model L100V) was fastened to an automotive platform jack (measure 36″ x 18″) with locking wheels that can be either raised or lowered to allow the engine to easily be transported. To reduce the vibrations while the engine is running, the platform jack was modified by adding a 1″ thick piece of Styrofoam to the surface followed by a section of painted high quality plywood (¾″ thickness). The plywood and foam were bolted at four corners with 3/8″ bolts affixed with flat and lock washers. The motor was centered and adjusted so that there was adequate room for a lawn tractor battery to power an electric starter attached to the engine. The battery measured 5″x 7″x 7″ and contained a crank power of at least 200 amps. Care must be taken when mounting the battery harness so that it is secure and will not vibrate loose. Additionally, the battery terminals should be insulated with caps. This particular engine model has an exposed shaft that revolves at an extremely high rate while in use. We affixed a custom made triangular metal guard (cage) with small openings to prevent clothing, foreign objects, and appendages from coming in contact with the rotating shaft during operation. Additionally, if the engine is bolted to an adjustable dolly platform (as we have described), it should be completely lowered and the wheels locked prior to starting the engine to prevent the cart from moving and reduce any items from being lodged between the platform and dolly base while the engine is in operation. The fuel drain plug on the gas tank was replaced with a valve and attached to an elongated copper tube to allow the fuel, following a lesson, to easily be removed (drained) prior to storage to prevent the fuel line and fuel injector from being clogged when the engine is stored for extended periods of time. This clogging may occur in as little as sixty days. To help prevent any clogging, 50 mL of diesel fuel stabilizer can be added to a tank of fuel if the engine is to be stored without being draining.

Relevance and Follow-up Activities

- Following the experiment, the students can be encouraged to interpret a full class set of data. This will serve as a good opportunity to engage the students in a discussion of accuracy and precision.
- The discussion of an alternative fuel was further enriched by watching the documentary *King Corn* by Aaron Woolf, Ian Cheney, and Curt Ellis, and then having the students review the supply of soybean and corn crops produced in the US.
- Finally, the students were challenged to view this activity as an introduction to possible scientific careers that could be both rewarding and revolutionary in addressing humanitarian issues.