Science

Biodiesel: Back to the Future

Overview

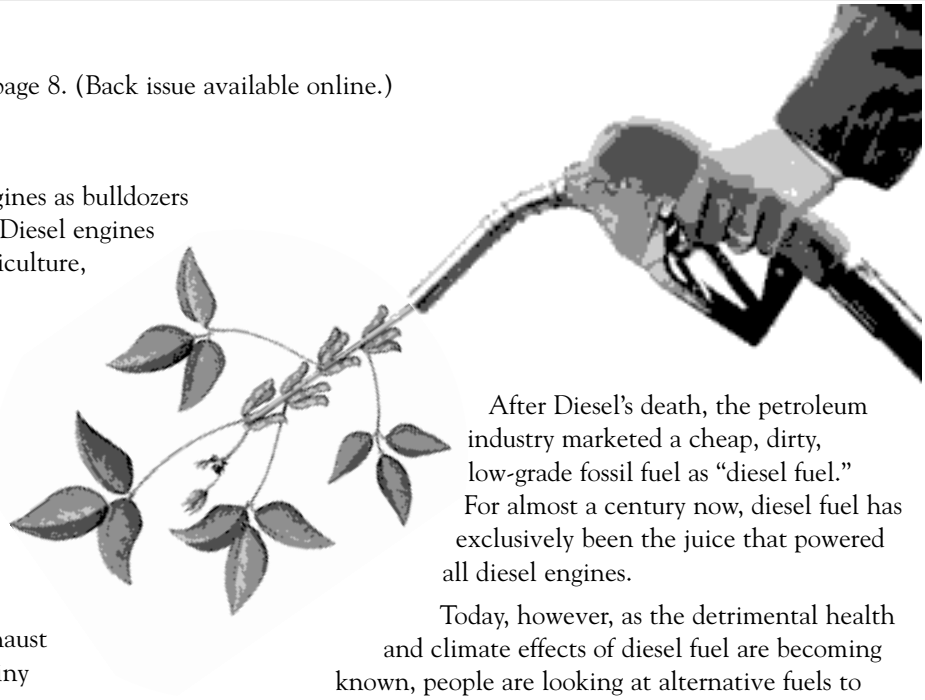
Students will:

- **Create a small batch of biodiesel. A titration will be performed if recycled cooking oil is used.**
- **Analyze a data chart that compares the emissions of various fuel types.**
- **Design a diagram comparing the carbon cycle of diesel fuel to that of biodiesel.**
- **Compare different biodiesel production and distribution models and discuss sustainability.**

Terrain Article:

"Liquid Solar," *Terrain*, Summer 2002, page 8. (Back issue available online.)

Introduction



Have you ever heard the growl of engines as bulldozers dug the foundation for a new building? Diesel engines are all around us, doing the work of agriculture, construction, and transportation. The rugged and durable diesel engine can handle extreme use such as frequent stopping and starting, towing heavy loads, or hauling cargo long distances.

Have you ever gotten trapped behind a bus as it pulled away, leaving you choking in the black cloud of smoke that spewed from its tailpipe? If you have, then you've had a first-hand taste of diesel fuel's downside: sooty exhaust full of cancer-causing compounds and tiny particles that lodge deep in your lungs.

In 1895, when German inventor Rudolf Diesel invented the diesel engine, he created an engine that was more efficient, reliable, and long-lasting than the other engines of that time. When Diesel first demostrated his engine at the World Exhibition in Paris, he used peanut oil as fuel.

After Diesel's death, the petroleum industry marketed a cheap, dirty, low-grade fossil fuel as "diesel fuel." For almost a century now, diesel fuel has exclusively been the juice that powered all diesel engines.

Today, however, as the detrimental health and climate effects of diesel fuel are becoming known, people are looking at alternative fuels to reduce emissions. One of the alternatives – vegetable oil – was what Rudolph Diesel had envisioned all along. In this lesson, you will learn about biodiesel – a renewable fuel made from processed vegetable oil – that is powering an increasing number of diesel vehicles and machinery. More lubricating than diesel fuel, biodiesel increases the life of diesel engines, is safe to handle, biodegradable, and non-toxic.

Diesel Engines

Biodiesel can be used in a diesel engine with little or no adaptation to the existing engine. A diesel engine takes in air, compresses it, then injects fuel into the compressed air. The heat of the compressed air ignites the fuel spontaneously. A gasoline engine takes in a mixture of fuel and air, compresses it, and ignites the mixture with a spark. A useful animation of a diesel engine may be found at auto.howstuffworks.com/diesel1.htm.

CA CHEMISTRY STANDARDS: Acids and Bases 5.d. Students know how to use the pH scale to characterize acid and base solutions. Chemical Thermodynamics 7.b. Students know chemical processes can either release (exothermic) or absorb (endothermic) thermal energy. Organic Reaction Rates 8.c. Students know the role a catalyst plays in increasing the reaction rate. Chemistry and Biochemistry 10.e. Students know how to identify the functional groups that form the basis of alcohols, ketones, ethers, amines, esters, aldehydes, and organic acids.

Emission Impossible

Worksheet/Activity

Students will compare the emissions of diesel fuel to other fuels, including biodiesel, by reading a data table, answering questions, and drawing diagrams.

Diesel Emissions

The gases contained in diesel exhaust include carbon dioxide, carbon monoxide, nitrous oxides, sulfur compounds, hydrocarbons, aldehydes, benzene, 1,3-butadiene, polycyclic aromatic hydrocarbons (PAHs), and nitro-PAHs. Diesel exhaust also contains **particulate** – tiny, airborne particles of solid matter that may be breathed deeply into the lungs.

The California Air Resources Board reported that diesel particulate appears to be responsible for over 70% of the cancer risk from air pollution exposure in California. Many components of diesel exhaust are known to cause cancer or be disruptive to the reproductive and endocrine systems. Diesel also contains chemicals that contribute to global warming, ozone formation, regional haze, and acid rain.

The Carbon Cycle

Plants transform solar energy into chemical energy in the form of hydrocarbons, which are stored in the oil of seeds. A hydrocarbon is a compound of hydrogen and carbon, often occuring as a long atomic chain in which each carbon atom has two hydrogen atoms attached to it. These chains release considerable energy when burned.

Both fossil fuels and biodiesel contain hydrocarbons. Gasoline and diesel come from plants which grew millions of years ago and are trapped in the earth, whereas biodiesel comes from the seeds of plants grown today for oil.

When fossil fuel hydrocarbons are burned, carbon that was otherwise locked below the earth's crust is combined with oxygen and expelled into the atmosphere as CO_2, adding to the greenhouse effect.

When biodiesel hydrocarbons are burned, the carbon from vegetable oil is also expelled into the atmosphere as CO_2. However, the plants grown to make the fuel will withdraw from the atmosphere roughly the same amount of CO_2 that the fuel's burning adds.

Comparing Emissions Per Mile

Fuel	Green-house Gases	Particulates	Nitrous Oxides	Volatile Organic Compounds	Carbon Monoxide
Gasoline	+35	-70	-55	+170	+415
CNG	+20	-80	-45	-30	+190
LPG	+20	-80	-60	0	+210
Ethanol 85%	0	-75	-55	+130	+210
Diesel	0	0	0	0	0
Biodiesel 20%	-15	-20	0	-10	-15
Hybrid	-30	-20	-20	-20	-20
Electric	-45	-80	-95	-100	-100
Biodiesel 100%	-70	-55	+5	-55	-45

The numbers in the data table at left reflect the percent difference for a vehicle traveling for a mile on a fuel as compared to a comparable vehicle travelling for a mile on diesel.

Emissions calculations take into account the entire fuel cycle, from fuel production to tailpipe emissions. Numbers are averages rounded to the nearest 5%. CNG refers to compressed natural gas. LPG refers to liquid petroleum gas.

This graph is from a July, 2001 report on alternative fuel technologies authored by the Alternative Fuel Vehicle Program and sponsored by HGCI, UOS, Ford Motor Company, and Harvard University.

Questions/Assignments

1. **Analyze the graph:** What fuel contributes the least amount of greenhouse gases to the atmosphere per mile? Why?
2. **Analyze the graph:** Local and state government agencies encourage schoolbus and public transit fleets to switch to running on CNG. How do CNG emissions compare to biodiesel emissions with regards to carbon monoxide? Extra credit assignment: Compare the cost of switching a diesel bus fleet to CNG to switching a bus fleet to biodiesel.
3. **Analyze the graph:** What emission component is present in greater quantities in biodiesel exhaust than in diesel exhaust? What are some other factors that should be taken into account when comparing fuels?
4. **Draw a diagram:** Design a poster that shows how diesel takes carbon trapped in the earth and adds it to the atmosphere, whereas biodiesel adds but also subtracts carbon from the atmosphere.
5. **Venture an opinion:** Should emissions be evaluated based upon what comes out of the tailpipe, or should they be evaluated based upon the whole life cycle of the fuel, from its production to its exhaust? Why?
6. **Venture an opinion:** Should governments offer incentives for people or industry to switch to cleaner-burning fuels? Why or why not? What kind of incentives would you suggest?

Brew a Batch of Biodiesel

Lab Demonstration

In this lab demonstration, teacher or students will create biodiesel through a transesterification process.

Materials Needed

- Scale
- Glass blender
- 1 container of unopened lye
- 1 liter un-used or used vegetable oil
- 200 ml of methanol (sold at hobby shops as fuel for model cars and planes. Use only 100% methanol.)
- Safety Wear: gloves, goggles, protective clothing
- Two 500ml beakers, two 1500ml beakers
- Litmus paper
- Petri dish
- Vinegar

Safety Precautions !!!

Workspace: Biodiesel is best made in a clean chemistry lab with adequate ventilation or outdoors with a hose and running water handy.

Materials: Do not use blender for food after mixing biodiesel. Use only glass containers for demonstration.

Clothing: Wear long pants, a long-sleeved shirt, and keep hair pulled back. No sandals. Wear safety goggles, gloves, and an apron.

Chemicals: Lye should be handled carefully. It can damage skin, eyes, and lungs and can be fatal if swallowed. Running water should be available to perform an eye wash in case a reactant splashes. Sodium methoxide is extremely caustic. Wash any body part that comes in contact with methanol or lye with vinegar and water. Do not inhale any vapors.

This lab involves the handling of dangerous chemicals. Please follow safety precautions.

Procedure

1. **Clear work space and put on protective goggles, gloves, and an apron.**
2. **If you will be using un-used vegetable oil, procede to step 3. If you will be using used vegetable oil, you must first perform the lab extension on page 9.**
3. **Measure out the reactants in separate containers.**
   - 1 liter of oil into a 1500 ml beaker
   - 200 ml of methanol into a 500 ml beaker
   - 3.5 grams of lye into a petri dish on a gram scale
4. **Make sodium methoxide (an extremely strong base).**
   - Put the blender together correctly and make sure the base is sealed tightly.
   - Carefully pour the methanol into the opened blender. If any spills, clean with wet paper towel and vinegar.
   - Carefully pour lye into blender, place top on blender, and blend at lowest setting until all the lye is dissolved.
5. **Immediately mix the reactants.**
   - Open the blender and put the top to the side. Keep your face away from the top of the blender.
   - Pour the vegetable oil into the blender.
   - Put the top back on the blender. Blend the reactants on medium setting for 15 minutes. If the blender motor or the container get excessively hot, turn the blender off.
6. **Allow the glycerine to settle.**
   - Unplug the blender and label it "Biodiesel reaction in progress. DO NOT DRINK." Wait at least 8 hours.
   - You will probably notice the mix separating quite a bit during the first hour.
7. **Separate the glycerin and the biodiesel.**
   - The glycerin will fall to the bottom of the blender. The layer of liquid on top of the glycerin is biodiesel. The top layer will be a lighter color than the bottom layer.
   - Using a ladle, scoop off the biodiesel and place it in a 1500 ml beaker. Do not stir up or scoop out any of the glycerin, which has settled to the bottom of the blender.
   - Check the finished product with pH paper. Quality biodiesel should be neutral (pH 7) and look like clear vegetable oil with a light brown tint, like apple cider.
8. **Clean up.**
   Clean the work area, store the leftover chemicals, and clean the equipment with a vinegar and water solution. Expose glycerin to air and sunlight for three weeks, then compost.

What's Happening in this Lab?

The process of making biodiesel from vegetable oil is called **transesterification**. A vegetable oil molecule (called a **triglyceride**) is three esters attached to a glycerin molecule. An **ester** is a hydrocarbon chain that will bond with another molecule. To make biodiesel, you must break or "crack" the triglyceride using a **catalyst** such as lye (NaOH). During this process, the glycerin molecule will break off the triglyceride and each of the three esters will attach to alcohol molecules. Methanol is the alcohol we'll be using. When the freed esters combine with alcohol molecules, they form **methyl esters**, or in other words, biodiesel.

$$C_3H_5(OOCR)_3 + 3CH_3OH \rightarrow 3RCOOCH_3 + C_3H_5(OH)_3$$

triglyceride methanol methyl ester glycerine

Questions

1. Does the process of transesterification release or absorb thermal energy? How do you know?
2. In the transesterification reaction, which of the reactants are basic?

Titration Extention for Used Oil

Lab Extension

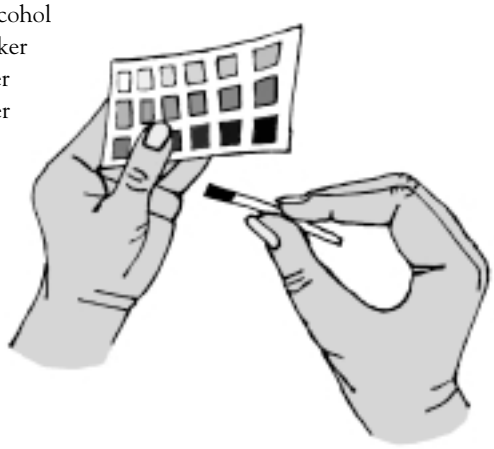
Biodiesel may be made using waste oil – vegetable oil that has already been used for cooking. However, if waste oil is used, the amount of catalyst (lye) must be adjusted. In this extension, students will calculate how much catalyst will be needed by performing a titration.

Why and How?

Restaurants in this country produce billions of gallons of used cooking oil. Biodiesel is one way to put this waste product to good use. Oil that has been used for cooking is more acidic than new vegetable oil. The heating process creates free fatty acids that float amongst the triglycerides. Titration is a method of determining how much lye is needed to neutralize the free fatty acids.

Additional Materials

- Conical paper coffee filter
- Graduated eyedropper
- Isopropyl alcohol
- 1500ml beaker
- 20ml beaker
- Litmus paper



Procedure

1. Pour used oil though a coffee filter to remove any food chunks that may be floating in it.
2. Measure 1 gram of lye onto a petri dish on a scale.
3. Measure 1 liter of distilled water into a 1500ml beaker.
4. Pour the 1 gram of lye into the 1 liter of water and label this beaker "lye/water: DO NOT DRINK."
5. Measure 10 ml of isopropyl alcohol into a 20 ml beaker.
6. Dissolve 1 ml of used vegetable oil into the isopropyl alcohol and label this beaker "oil/alcohol."
7. Use a graduated eyedropper to drop 1 ml of the lye/water solution into the oil/alcohol solution.
8. Check the pH of the oil/alcohol solution with a strip of litmus paper. Compare the litmus strip's color with the color chart to get an immediate pH reading.
9. Repeat steps 7 and 8, counting the milliliters of lye/water you add until the oil/alcohol reaches a pH of between 8 and 9. The pH may rise suddenly. You will probably add no more than 3 ml of lye/water.
10. Use the following equation:
    - total ml of lye/water dropped into oil/alcohol = (x)
    - (x + 3.5) = L
    - L = the number of grams of lye needed to neutralize and react one liter of used vegetable oil. (*L will usually be between 4.5 and 6.5, but it may be higher if the oil has been used for a long time.*)
11. You may now do the lab on page 8, using L grams of lye instead of the 3.5 grams of lye called for.

The Business of Biodiesel

Class Discussion A

Students will compare the various business models used to produce and distribute biodiesel.

Directions

For reasons such as lower emissions and longer engine life, biodiesel is a desirable product. Read the business models at right that describe how the fuel is produced and made available to customers. Then discuss the questions below.

1. Which of the models do you think best serves the purpose of getting more people to use biodiesel? Why?
2. Which scenario is most environmentally sound? Why?
3. In each model, who or what do you think will dictate the price of the fuel?
4. Which of the scenarios is best in terms of ensuring a reliable supply of biodiesel, even in times of national or international crises? Why?
5. Which model requires that the oil and the biodiesel travel the least distance to reach the user?
6. What are the benefits of individuals having the means to produce and control their own energy source?
7. Which method of obtaining biodiesel would you personally use and why?

Biodiesel Business Models

Model A: *A multinational oil corporation produces biodiesel on a large scale and distributes it to gas stations across the US. The corporation contracts with a large corporate grower to produce soybeans for soy oil. Growers usually grow genetically modified crops using conventional methods.*

Model B: *Local co-op of biodiesel users produces biodiesel using waste oil obtained free from local restaurants. The co-op is owned by its members, who contribute some of their time to help with used oil collection or fuel production in exchange for a supply of biodiesel.*

Model C: *Small, privately-owned company makes biodiesel from virgin oil or used restaurant oil and distributes it via delivery truck to farmers and businesses within a 200 mile radius. They also operate two fueling stations in nearby towns.*

Model D: *A small corporation produces biodiesel from used restaurant grease. The fuel is made at three different plants and distributed in three states to large, industrial users. The company offers kitchen grease pick-up services to restaurants and sells several other products made from waste oil.*

Sustainability: What Is It?

Class Discussion B

Students will discuss the concept of sustainability and apply their understanding to the issue of biodiesel versus fossil fuel use.

Directions

Teacher: "Sustainability" is a buzzword that is getting lots of use these days. Before proceding to the discussion questions, ask your class what they think "sustainability" really means. Write their ideas on the board. Below are some ideas that you may suggest to spur brainstorming.

- Not consuming more resources than are being replenished.
- Providing a safe, healthy, high quality of life for current and future generations.
- Using methods or approaches that can be used effectively and dependably into the future.
- Employing practices that protect the natural resource base and don't threaten the natural systems on which all life depends.
- Developing attitudes and ongoing actions that strengthen the natural environment, the economy, and social well-being.

Discussion Questions

1. What would it mean for a fuel to be "sustainable"?
2. Can petroleum companies continue to meet our fuel needs into the forseeable future?
3. Can oil-bearing crops and restaurant grease meet our fuel needs into the forseeable future? (Is there enough arable land to grow the necessary crops? Are there enough restaurants to provide used cooking oil?)
4. Where are the primary reserves of fossil fuels located? Currently, how are we going about trying to obtain them? Are our current methods of securing access to oil reserves sustainable?
5. Are the greenhouse gases that trucks and autos contribute to the atmosphere sustainable?
6. When you buy fossil fuel, over 30% of the money you spend goes overseas. This transfer of money contributes to the US trade deficit, which reached a record high in 2003. Is a growing trade deficit, fueled by our dependence on foreign oil, sustainable for our economy?
7. Untapped fossil fuels reserves are found in a limited number of places and controlled by a limited number of companies and countries. What does this mean for the sustainability of this fuel supply?

Biodiesel Uses and Users

Some of the ways biodiesel *can* be used:

Biodiesel can be used to power diesel cars, diesel trucks, diesel RVs, catapillars, cement trucks, dumptrucks, bulldozers, spreaders, front loaders, cranes, backhoes, graders, generators, tractors, reapers, tillers, pickers, conveyors, pumps, irrigation systems, power plant generators, oil furnace generators, mining trucks, ore cars, and diesel trains. It can be used as a biodegradable, nontoxic cleaner to clean up wildlife affected by oil spills, to remove paint, and to clean sludge in tanks that have been used for Diesel #2. It can be used as a lubricant for machines big and small, from trucks and buses to sewing machines.

Some of the ways biodiesel is *already* being used:

- US Post Office fleet
- Tour bus for Indigo Girls
- Generators at Lollapalooza festivals
- Berkeley's Ecology Center recycling trucks
- National Parks Service's boats and vehicles
- Schoolbuses in Deer Valley School District, AZ
- European motorists use 250 million gallons every year. France is the world's largest producer.
- Public buses in the St. Louis area, Northern Kentucky, and Breckenridge, Colorado
- Sierra Railroad's train engines
- Splash Tours' amphibious tour fleet in San Francisco

Q: How would you put biodiesel to use if given the chance?

Get Involved: Practical Participation

My First Car Smells Like French Fries! Consider buying a used diesel car and running it on biodiesel. A used diesel Volkswagon from the 1980's can cost as little as $1000. To find a biodiesel pump near you, go to www.biodiesel.org/buyingbiodiesel/retailfuelingsites. Unlike gasoline, biodiesel is nontoxic, so storing a supply in your garage or backyard is safe.

Biodiesel for your Boating Friends: If you know anyone who owns a boat, ask them whether their boat has a diesel motor. Tell them what you know about the benefits of biodiesel. Offer to find for them the nearest place to purchase biodiesel.

Schoolbus Activism: Get a petition started to ask your school district to switch to using biodiesel in its schoolbuses as a way to protect student health.

Restaurant Runner: Volunteer to collect restaurant grease for a local biodiesel cooperative. You can scout new sources of used oil for them by asking neighborhood restaurants if they would donate their grease.

Recommended Biodiesel Websites

- **www.journeytoforever.org/biodiesel.html**
- **www.cytoculture.com/Biodiesel%20Handbook.htm** ***(good site to research marine biodiesel use)***
- **www.biodiesel.org** ***(includes listing of US fueling sites)***
- **www.veggievan.org**