RICK STROMBOSKI

Do You Want Biodiesel With That?

By Mary Kirchhoff

Maybe you've heard the story—using oil from a fast food restaurant or local greasy spoon to run your car (and the French fry smell of the exhaust makes you hungry!) Is this for real or something cooked up by the tabloids to get your attention? How can cooking oil get you to the mall for some serious shopping on a Saturday night?

Used cooking oil by itself is not a great fuel, especially not straight out of the deep fryer—but converting cooking oil to biodiesel provides an alternative to gasoline. Biodiesel is the general name given to a variety of cleaner-burning fuels made from different animal and vegetable oils, such as soybean and sunflower oils. Because most of these oils come from plants, biodiesel can be made from renewable resources. Biodiesel offers several advantages over diesel: it burns cleaner, is biodegradable, and is nontoxic.

The diesel engine (invented by Dr. Rudolph Diesel over 100 years ago) is used in buses, trucks, farm equipment, and some cars. You may have noticed a separate pump for diesel the last time you were at the gas station. Both gasoline and diesel are made from crude oil—so what's the difference between them? The hydrocarbon chains in diesel fuel (10–20 carbons) are longer than those in gasoline (5–10 carbons). Dr. Diesel used a variety of fuels to run his engine—in fact, when he unveiled his invention at the World Exhibition in 1900, it ran on peanut oil! Existing diesel engines do not need to be modified in switching from diesel to biodiesel as the fuel. You just pump and go!

Why do some cars use gasoline while others run on diesel? The answer lies in the different types of engines used in these vehicles. Diesel engines are compression ignition engines. When air is quickly and dramatically compressed, its temperature rises. In a diesel engine the air in the combustion chamber is compressed to such an extent that it becomes quite hot—hot enough to ignite the fuel that is then injected into the chamber. No external spark is required. In contrast, a spark ignites the fuel/air mixture in a gasoline, or spark ignition, engine. Because of the difference in how the engines work, diesel engines can use thicker fuels than gasoline engines.

Soybean oil and used cooking grease are the primary sources of biodiesel in the United States. Soybeans are about 20% oil by weight, and approximately 7.3 pounds of soybean oil are needed to produce one gallon of biodiesel. This means that 36.5 pounds of soybeans are required to make one gallon of biodiesel. On the plus side, you can grow a new crop of soybeans each year (try doing that with crude oil!) Currently, biodiesel is available in about half the country.

Transesterification—the biodiesel reaction

Biodiesel is made simply by heating vegetable oil with an alcohol, usually methanol (CH_3OH) or ethanol (CH_3CH_2OH), in the presence of a catalyst, such as sodium or potassium hydroxide. Vegetable oil is a triglyceride that undergoes a transesterification (converting one ester into another) reaction in forming biodiesel. The byproduct of this reaction, glycerol, is an ingredient in numerous consumer products, including pharmaceuticals and makeup.

What are the environmental benefits of biodiesel? Burning biodiesel does not result in a net increase in carbon dioxide (CO_2) in the atmosphere. You're familiar with carbon dioxide—it's the gas you exhale during respiration and the gas that puts the fizz in soda pop. Carbon dioxide is also a gas that is linked to global warming, the gradual heating of the Earth, due in large part to the combustion of fossil fuels. Energy sources that do not add more CO_2 to the atmosphere are better for the environment.

GETTY IMAGES

Biodiesel can be made from waste vegetable oil.

The use of biodiesel can dramatically reduce the amount of carbon dioxide released into the atmosphere. This is environmentally beneficial. Although biodiesel releases CO_2 into the atmosphere when burned, CO_2 was absorbed from the atmosphere to grow the plants used to make the biodiesel. These two effects basically cancel each other, and although biodiesel fuel is often blended with regular diesel fuel, there still remains a significant reduction in the net release of CO_2.

NATIONAL BIODIESEL BOARD

Biodiesel filling stations are cropping up all over the place. If your car runs on diesel, you can use biodiesel too!

Biodiesel offers several safety advantages. First, it has a higher flash point than regular diesel, meaning it won't ignite as easily. The flash point for biodiesel is 300 °F, compared with 125 °F for petroleum diesel. Second, it's as biodegradable and nontoxic as vegetable oil; in case of an accidental spill, biodiesel will not persist in the environment.

Biodiesel is one of the alternative fuels identified in the Energy Policy Act (EPAct), passed in 1993 and amended in 1998 to include biodiesel. EPAct addresses the need to improve both our energy security and environmental quality. It encourages the use of alternative fuels, including ethanol, natural gas, hydrogen, and propane. Under EPAct, federal and state governments are required to include alternative fuel vehicles in their fleets of light-duty vehicles.

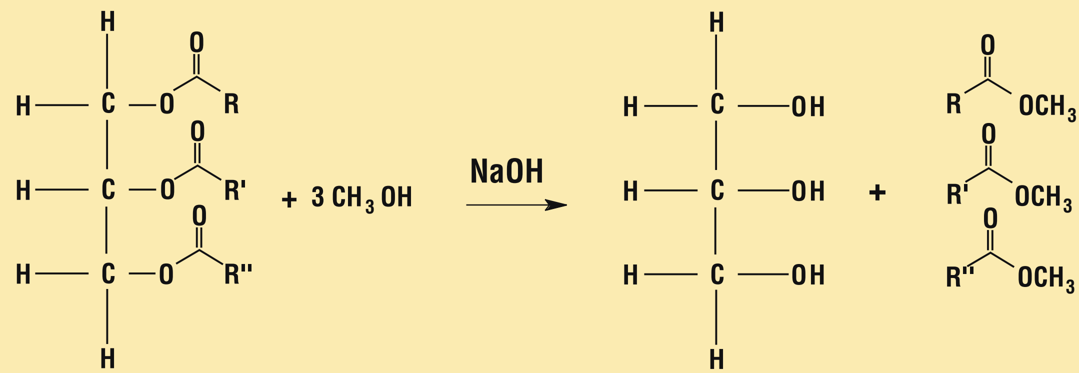
Who uses biodiesel?

In the United States, the military is the largest consumer of biodiesel. The Defense Energy Support Center coordinates the federal government's fuel purchases and has been using B20 to fuel vehicles on a number of bases for the past three years. B20 is a blend of 20% biodiesel with 80% petroleum diesel. School buses in Las Vegas, NV, also use B20. Casinos in Las Vegas contribute their waste grease (about 6 gallons per resident per year) to make biodiesel, which fuels over 1,200 of the district's school buses.

Yellowstone National Park has adopted a "Greening the Environment" program that includes the use of biodiesel in its diesel trucks. An issue unique to Yellowstone was bears—would the French fry odor of the fuel attract bears? The "bear attraction test" demonstrated that this was not the case; trucks using biodiesel will not be attacked by bears craving French fries!

Many other countries are taking advantage of biodiesel. Rapeseed oil is the source of most of the biodiesel produced in Europe, which has been using biodiesel for more than 20 years. Germany is the largest biodiesel market in the world, consuming more than 1 million metric tonnes (1000 kg) in 2004. Members of the European Union are planning to use biodiesel to meet 2% of their fuel needs in 2005, with a target of 5.75% in 2010.

Transesterification—the biodiesel reaction



Vegetable oil + Methanol $\xrightarrow{\text{Catalyst}}$ Glycerol + Methyl esters *(Biodiesel)*

Not just vegetable oil

Vegetable oil is not the only source of biodiesel, however. A project in Alaska uses fish oil to make biodiesel blends for use in generator engines, a power source for many rural areas in Alaska. The Unalaska/Dutch Harbor community in the Aleutian Islands produces 3.5 million gallons of fish oil each year. Pure fish oil and 50:50 blends of fish oil and diesel fuel have been tested, with the blends delivering comparable performance to straight diesel fuel. Fish oil blends make economic sense, too, for local residents in Alaska—fish oil sells for 25¢ per gallon, while diesel has been retailing at more than $2 per gallon.

If biodiesel is better for the environment, why aren't we filling up our cars and trucks with it? Cost is one factor—even at $2 per gallon, gasoline and conventional diesel are still cheaper than commercially made biodiesel.

Another difficulty in using biodiesel is that it is more viscous (thicker) than gasoline. This can be a problem in cold climates, where your fuel can turn into a gel in the winter. Biodiesel also has about a 10% lower energy content than petroleum diesel. And while carbon dioxide emissions decline, emissions of nitrous oxides (NO_x), which contribute to air pollution, may increase.

The benefits of biodiesel have prompted increased investment in this alternative fuel. The potential market for biodiesel led to the recent announcement by Blue Sun Biodiesel that it will construct the first high-volume blending terminal and processing plant in the United States. With support from the U.S. Department of Agriculture, this plant will be built in Alamosa, CO, near the San Luis Valley. This agricultural region will supply the canola oil needed to make biodiesel blend B20. The plant should be completed in May 2005.

NATIONAL BIODIESEL BOARD

Biodiesel is often mixed with petroleum diesel to make its price closer to conventional diesel. At the pump B100 is pure biodiesel. B20 is 20% biodiesel.

Green chemistry

Using biodiesel to run a car or power a generator illustrates one of the basic principles of green chemistry, the use of renewable starting materials. Green chemistry focuses on designing chemical products and processes that are more environmentally friendly. We know that petroleum is a nonrenewable resource, which we will run out of at some point. Developing alternatives to petroleum-based fuels, such as biodiesel, may provide us with a long-term, renewable energy source.

So, the next time you're eating some French fries at your favorite fast food restaurant, think about the grease that was used to cook those fries. Instead of being thrown out, it may be converted into biodiesel to fuel your car!

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ChemMatters

April 2005 Teacher's Guide

"Do You Want Biodiesel With That?

Student Questions

Do You Want Biodiesel With That?

1. What do the chemical formulas for regular gasoline and diesel fuel have in common? In what way do they differ?
2. Describe how the operation of a diesel engine compares to that of a gasoline engine.
3. What are the two main sources of biodiesel in the United States?
4. What is one of the environmental benefits attached to the use of biodiesel in place of regular diesel fuel or gasoline? Explain how this benefit arises.
5. Describe two other advantages attached to the use of biodiesel.
6. What is meant by the term "B20" when it is attached to a fuel containing biodiesel?
7. List four disadvantages of using biodiesel fuel.
8. What is the major goal of the "Green Chemistry" movement?

Answers to Student Questions

Do You Want Biodiesel With That?

1. What do the chemical formulas for regular gasoline and diesel fuel have in common? In what way do they differ?

   Both gasoline and diesel fuel consist of a mixture of hydrocarbons, but the hydrocarbon chains in diesel fuel are about 10-20 carbon atoms long, while the hydrocarbon chains in gasoline are only about 5-10 carbon atoms long.

2. Describe how the operation of a diesel engine compares to that of a gasoline engine.

   Diesel engines use what is called compression ignition. In a diesel engine the air in the combustion chamber is quickly and dramatically compressed. This causes the air to become so hot that it can ignite the fuel that is then injected into the chamber. No external spark is required. In a gasoline engine the air is mixed with the fuel inside the combustion chamber and then ignited with a spark.

3. What are the two main sources of biodiesel in the United States?

   Soybean oil and cooking grease.

4. What is one of the environmental benefits attached to the use of biodiesel in place of regular diesel fuel or gasoline? Explain how this benefit arises.

   Burning biodiesel significantly reduces the amount of carbon dioxide that is added to the atmosphere when the fuel is burned, and carbon dioxide has been linked to global warming. Although burning biodiesel does release CO_2 into the atmosphere, CO_2 was absorbed from the atmosphere when the plants used to make the biodiesel were grown. These two effects basically cancel out, and although biodiesel is often blended with regular diesel fuel, there is still a significant reduction in the net release of carbon dioxide.

5. Describe two other advantages attached to the use of biodiesel.

   Biodiesel is safer to use, because it has a higher flash point (300 ^oF), compared to that of regular petroleum diesel (125 ^oF). This means that it won't ignite as easily. In addition, it is as biodegradable and nontoxic as vegetable oil, so if it is spilled, it won't persist in the environment.

6. What is meant by the term "B20" when it is attached to a fuel containing biodiesel?

   B20 means that the fuel consists of a blend of 20% biodiesel with 80% petroleum diesel.

7. List four disadvantages of using biodiesel fuel.

   (1) It is more expensive.

   (2) It is more viscous (thicker), which can be a problem in cold climates—the fuel can turn into a gel in the winter.

   (3) It has about a 10% lower energy content than petroleum diesel.

   (4) It may result in higher emissions of nitrous oxides (NO_x).

8. What is the major goal of the "Green Chemistry" movement?

   Green chemistry focuses on designing chemical products and processes that are more environmentally friendly.

Content Reading Guide

National Science Education Content Standard Addressed As a result of activities in grades 9-12, all students should develop understanding	**Biodiesel**
Science as Inquiry Standard A: about scientific inquiry.	✔
Physical Science Standard B: of the structure and properties of matter.	✔
Physical Science Standard B: of chemical reactions.	✔
Physical Science Standard B: of conservation of energy and increase in disorder	
Physical Science Standard B: of the interaction of energy and matter.	✔
Life Science Standard C: of matter, energy, and organization in living systems.	✔
Earth & Space Science Standard D: of geochemical cycles.	✔
Science and Technology Standard E: about science and technology.	✔
Science in Personal and Social Perspectives Standard F: of personal and community health.	✔
Science in Personal and Social Perspectives Standard F: of natural resources.	✔
Science in Personal and Social Perspectives Standard F: of environmental quality.	✔
Science in Personal and Social Perspectives Standard F: of natural and human-induced hazards.	
Science in Personal and Social Perspectives Standard F: of science and technology in local, national, and global challenges.	✔
History and Nature of Science Standard G: of science as a human endeavor.	✔
History and Nature of Science Standard G: of the nature of scientific knowledge.	✔
History and Nature of Science Standard G: of historical perspectives.	

Anticipation Guides

Anticipation guides help engage students by activating prior knowledge and stimulating student interest before reading. If class time permits, discuss their responses to each statement before reading each article. As they read, students should look for evidence supporting or refuting their initial responses.

Directions for all Anticipation Guides: In the first column, write “A” or “D” indicating your agreement or disagreement with each statement. As you read, compare your opinions with information from the article and complete the second column. In the space under each statement, cite information from the article that supports or refutes your original ideas.

Do You Want Biodiesel With That?

Me	Text	Statement
		1. If you want to use biodiesel in your diesel engine, you must get a converter kit.
		2. Biodiesel is now available commercially in the United States.
		3. Burning biodiesel fuel can help reduce the amount of CO_2 in the atmosphere.
		4. Biodiesel is safer to use than regular diesel.
		5. The largest consumer of biodiesel in the United States is the National Parks System.
		6. Biodiesel can be produced from fish oil.

Reading Strategies

These content frames and organizers are provided to help students locate and analyze information from the articles. Student understanding will be enhanced when they explore and evaluate the information themselves, with input from the teacher if students are struggling. If you use these reading strategies to evaluate student performance, you may want to develop a grading rubric such as the one below.

Score	Description	Evidence
4	Excellent	Complete; details provided; demonstrates deep understanding.
3	Good	Complete; few details provided; demonstrates some understanding.
2	Fair	Incomplete; few details provided; some misconceptions evident.
1	Poor	Very incomplete; no details provided; many misconceptions evident.
0	Not acceptable	So incomplete that no judgment can be made about student understanding

Do You Want Biodiesel With That?

To complete the chart, contrast diesel and biodiesel fuels, then list the similarities in the bottom frame.

Diesel	Biodiesel
Similarities	

Do You Want Biodiesel with That?

Background Information

More about Rudolph Diesel and his engine

Born in Paris, France, on March 18, 1858, Diesel was trained as an industrial engineer. By 1880 he was building steam engines. Steam engines were notoriously inefficient, converting only about 10% of the energy from the fuel they burned into useful work. Diesel was convinced that a more efficient engine could be built. He theorized that if air were sufficiently compressed, its temperature would rise to the point where any fuel injected into an ignition chamber containing this hot air would spontaneously ignite. The resulting explosion would be capable of driving the piston downwards and the motion of this piston could then be harnessed to propel a vehicle or perform other useful work.

By 1893 he had built his first working model. It ran with an efficiency of 26%, a remarkable improvement from that provided by steam engines. By 1897 he had improved the design to where efficiencies of up to 75% were achievable.

By 1900 Diesel was ready to exhibit his new engine at the 1900 Paris Exposition. It was fueled by 100% peanut oil and received the Grand Prix.

Diesel intended and assumed that his engine would operate on biomass. He envisioned that farmers, small industries and those in isolated communities would be capable of producing their own fuel, and this would provide competition to the large monopolies that controlled all energy production at that time. He stated, “The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it.”

As it turned out, vegetable oils were indeed used as the fuel for diesel engines until about the 1920s. Around that time diesel engine manufacturers modified the injection system of the engine so it could run on lower viscosity fossil fuels. This was advantageous because fossil fuels were plentiful and relatively low in cost. An argument can also be made that the oil tycoons of that time utilized their significant influence to push events in that direction.

Diesel suffered an untimely and controversial death in 1913. He was traveling across the English Channel when he disappeared over the side of the ship. His body was recovered ten days later from the water, but the cause of his demise was never firmly established. There are some who argue that he was murdered for political reasons. The French navy was already using diesel engines, and, as the argument goes, may not have wanted the English navy to acquire them. Diesel was also opposed to the politics of Germany at that time, and did not want the German navy to be able to utilize his engine. After his death the entire German submarine fleet was powered by diesel engines.

But a case can be made that Diesel actually committed suicide. He evidently was troubled for much of his life. One historian describes him as being vain, oversensitive and a bit paranoid. There is that old joke that just because you’re paranoid doesn’t mean that people aren’t out to get you, and in Diesel’s case, that may have been true.

There is little doubt that Diesel deserves credit for being the first person to elucidate the basic principles that underlie the operation of the engine, which Diesel worked out from his knowledge of thermodynamics. He also built the first working models, although some have been described as being “catastrophic failures”. By around 1897 Diesel thought, probably mistakenly, that he was done with “inventing” the engine, and all that remained was some additional development. In fact, the engine required significant additional improvement before it would actually be ready to be marketed. It took about eleven additional years of improvements and innovations before a practical diesel engine was truly available. During this time Diesel basically had a nervous breakdown from the stress connected with trying to promote an engine that wasn’t really ready for widespread and practical use.

Diesel felt that he had done all the real work and invention, and denigrated the work of many other talented engineers who tried to improve the design and make it commercially feasible. He evidently was terribly troubled by the criticism and controversy when he vanished.

How a diesel engine works

If any students are interested in learning more about how a diesel engine works and how its operation compares to that of a normal gasoline-powered internal combustion engine, there is an animated Website that does an excellent job of explaining and demonstrating all of this. It can be found (with additional links) at:

http://www.howstuffworks.com/diesel.htm

The main differences between a gasoline engine and a diesel engine are probably:

In a gasoline powered engine a mixture of vaporized gasoline and air is first compressed and then ignited with a spark. A diesel engine does not require a spark. It simply compresses the air to such an extent that its temperature rises to the point where the fuel spontaneously ignites when it is injected into the chamber containing the compressed air. To achieve this higher temperature upon compression, the compression ratio (ratio of the volume of the cylinder before compression to the volume after compression) in a diesel engine ranges between about 14:1 to 25:1, whereas in a gasoline engine it only ranges from about 6:1 to 12:1.

Gasoline engines mix the air and fuel either by utilizing a carburetor, which mixes the air and fuel before they enter the cylinder, or fuel injection, in which case the fuel is injected outside the cylinder just before the intake stroke. In a diesel engine the fuel is injected directly into the combustion cylinder.

Comparing regular (not biodiesel) diesel fuel and gasoline

Compared to gasoline, diesel fuel is thicker (higher viscosity) and oilier. It evaporates much more slowly than gasoline and has a higher boiling point. When burned, diesel fuel releases more energy than a comparable volume of gasoline. Burning one gallon of diesel fuel will release about 155 million Joules of energy, compared to 132 million Joules for a gallon of gasoline.

Composition of biodiesel

First, it should probably be pointed out that blends of biodiesel and regular petroleum-based diesel fuel (such as B20) are technically not classified as biodiesel. They should be called biodiesel blends. That said, in practice it is probably somewhat common to refer to these blends as being “biodiesel” fuel, even though the majority of the fuel is actually composed of normal petroleum-based diesel and technically the name is being used inappropriately.

As the article points out, the term *biodiesel* does not refer to a specific material—similar to what is true for the term *gasoline*. Gasoline is not a pure substance. It is a mixture of various hydrocarbons and comes in various grades. Biodiesel, and biodiesel blends are general terms that refer to any fuels designed to be used by a diesel engine and comprised, at least in part, of oils derived from plant or animal sources other than petroleum.

Like gasoline, regular diesel fuel derived from petroleum is a mixture of several different hydrocarbons. The specific composition will vary. There are different kinds of diesel fuel, so it is not really possible to state with specificity and confidence what the composition of any particular fuel might be. The number of carbon atoms in the various hydrocarbons contained in diesel fuel may vary within the range of 9-23, i.e., C_9H_{20} to $C_{23}H_{48}$, but the amounts at the extreme ends is, at best, very low, so the range of 10-20 carbon atoms stated in the article is a reasonable representation.

The percentage of non-petroleum oil in biodiesel blends can range from very little to, in principle, 100%. One of the most commonly used formulations, B20, consists of a blend of 20% non-petroleum oil and 80% normal diesel fuel.

Advantages and disadvantages of biodiesel

There are obvious advantages to the use of biodiesel, many of which are pointed out in the article. Included among these are:

It is made from renewable resources such as soybeans or recycled cooking oils from restaurants.

There is an overproduction of soybeans in the United States. Using more biodiesel could provide a good use for some of this excess production.

It is less polluting than petroleum diesel. It emits less soot, carbon monoxide, unburned hydrocarbons and sulfur dioxide.

The absence of sulfur in 100% biodiesel is expected to result in an extension of the life of catalytic converters.

It can be used in combination with heating oil in residential and industrial buildings.

Blends of 20% biodiesel with 80% petroleum diesel can be used in unmodified diesel engines. The use of pure biodiesel fuel usually requires that modifications be made in the engine to avoid both performance and maintenance problems.

It has lubricating effects that may extend the lifetime of engines.

It is nontoxic and biodegradable.

It has a higher cetane (above 100) number than petroleum-based diesel fuel (about 40). The cetane number measures a fuel's iginition quality. The higher cetane numbers for biodiesel fuel are beneficial for cold starting and low idle noise.

It reduces our dependence on foreign oil.

Of course there must also be some disadvantages. Otherwise there wouldn't be any reason to use petroleum diesel at all. Some of the disadvantages are:

It is more expensive than petroleum diesel—about 50% more expensive. Part of the difference arises from the fact that soybeans are only about 20% oil. This cost can be reduced if it is made from recycled cooking oil or a plant that contains a higher percentage of oil.

It takes energy to grow and harvest the soybeans that are used to produce the diesel fuel.

It can cause damage to the rubber hoses in some engines, especially those built before 1994.

It cleans dirt from the engine. This sounds like a good thing, but the dirt then tends to clog fuel filters, especially when biodiesel is used in an engine for the first time.

It is not as widely distributed, so it can be somewhat difficult to obtain. This problem should lessen as the fuel becomes more widely utilized.

It is a good solvent. It will dissolve paint, so it shouldn't make contact with the body of a vehicle for any length of time.

It gels faster than petroleum in cold weather when used in its pure form.

Because it is partially oxygenated, biodiesel contains approximately 10% less energy content that a hydrocarbon/petroleum diesel.

More about the Energy Policy Act (EPAct)

The EPAct of 1993 required companies with fleets of at least 50 vehicles weighing 8,500 pounds or more to acquire alternative fuel vehicles. This evidently represented a burden in many cases, as compliance would require the purchase of new vehicles when the companies already possessed vehicles that ran well on normal diesel fuel. Consequently the act was amended in 1998 to allow the use of B20 fuel, which can be burned in a normal diesel engine without modifications.

This modification had immediate effects. Between 1999 and 2000 the use of blended biodiesel fuel increased dramatically. Biodiesel is also the only alternative fuel that has passed the EPA's Tier I and Tier II Health Effects Testing under the Clean Air Act. Other bio-fuels such as ethanol have only passed Tier I.

Connections to Chemistry Concepts

An understanding of the details of how biodiesel is made from vegetable oil requires some knowledge of organic chemistry functional groups, nomenclature and reactions. A good Website covering organic nomenclature can be found at: http://people.ouc.bc.ca/woodcock/nomenclature/

The URL for the IUPAC is: http://www.acdlabs.com/iupac/nomenclature/

Possible Student Misconceptions

Students may not understand the difference between a regular gasoline-powered internal combustion engine and a typical diesel engine. They probably do not understand the differences in how the fuel is ignited and how the differing compression ratios allow for this difference. See *Background Information*.

Because the article is basically devoted to the benefits and possibilities connected to the use of biodiesel, students may erroneously assume that the fuel offers nothing but benefits and that it is simply inertia that keeps it from being more widely used. Of course there are disadvantages as well. See *Background Information*.

Students may think that any blend of biodiesel with regular diesel is classified as being "biodiesel." Technically this is not the case. Although the term "biodiesel" is often casually assigned to blended fuels, only fuels made from 100% biodiesel should actually be called biodiesel.

Demonstrations and Lessons

1. If your course includes a discussion of bond energies and estimating enthalpies of reaction from bond energies, you could assign the following problem:

   The density of gasoline is 0.78 g/mL. The density of regular diesel fuel is 0.85 g/mL. A gallon is equal to about 3.8 L. Given the following average bond dissociation energies:

   C-C (347 kJ/mol)
   C-H (413 kJ/mol)
   O=O (495 kJ/mol)
   C=O (799 kJ/mol)
   H-O (467 kJ/mol)

   and assuming that gasoline can be represented by the formula C_8H_{18} and diesel fuel by the formula $C_{14}H_{30}$, estimate the number of Joules of energy that would be released when one gallon of gasoline and one gallon of diesel fuel are burned. Assume the only products of the reactions are gaseous carbon dioxide and water vapor.

   Alternately, even less information could be given and students could be expected to look up or calculate some of the required information. Stating the problem with minimal information one might ask:

   Using average bond dissociation energies, estimate and compare the amount of energy released when one gallon of gasoline and one gallon of diesel fuel are burned. Assume their respective formulas are C_8H_{18} and $C_{14}H_{30}$ and the only products of the reactions are carbon dioxide and water vapor.

   If you would like the solution to either or both or these problems, please send an email to chemtchur@aol.com, using the title, "Solutions to Biodiesel Problems." Replies can only be made to your school email address for obvious reasons.

2. Since the manufacture of biodiesel from vegetable oil is a transesterification process, this would be an excellent time to run an activity designed to have students prepare various esters in the laboratory. The ChemCom curriculum has a lab connected to this in the petroleum unit.

Connections to the Chemistry Curriculum

This article can connect with several commonly taught topics. Organic chemistry clearly heads the list, as the composition and synthesis of biodiesel immediately gets one into organic structures and reactions, especially esterification.

The properties of biodiesel can connect to concepts such as viscosity, flash point and the energy released in combustion reactions. See *Demonstrations and Lessons*.

Suggestions for Student Projects

1. Almost every class contains one or more students who have a strong interest in and perhaps knowledge of automobiles. These students might want to prepare an illustrated report on how the operation of

gasoline-powered internal combustion engines compares and contrasts to the operation of a diesel engine. See *Background Information*.

2. The continuing and even increasing dependence of the United States on foreign oil has serious economic and political consequences. Students could prepare a report tracking our increasing use of oil over the past century or so, and how changes in the availability and price of oil have affected the United States. This could be followed by a discussion of the extent, both ideally and practically, to which the use of biodiesel fuel might alleviate some of the problems tied to our significant dependence on foreign sources of petroleum.

Anticipating Student Questions

Is biodiesel being widely used in the United States at the present time?

It is difficult to obtain accurate data, since it is changing rapidly, but it is probably reasonable to say that its use is increasing rather significantly. Some sources estimate that its use will double in a relatively short period of time. Use of biodiesel rose from 500,000 gallons in 1999 to 20 million gallons in 2001. The United States Senate passed a bill in early 2002 that lifted a restriction that limited government vehicles to using biodiesel for no more than half of their alternative fuel requirements. This was considered significant because government vehicles represent a very significant consumer of biodiesel fuel.

Some of the major fleets currently making some use of biodiesel include:

The U.S. Department of Agriculture

The U.S. Postal Service

The U.S. military

The U.S. Department of Energy

State fleets in Iowa, Ohio, Delaware, New Jersey and Virginia

Public utility fleets like Duke Energy, Alabama Power and Commonwealth Edison

National Park Service

More than 100 cities have test projects or have run demonstrations involving more than 1,000 buses and over a million miles using biodiesel.

Do most engines using biodiesel fuel use it in its pure form?

No. It is mixed with normal petroleum diesel. A typical mixture will contain between 2-20% biodiesel, with the upper limit being most typical. Biodiesel fuels are labeled with a number that designates the percent of biodiesel in the mixture. For example, a fuel labeled B20 would contain 20% biodiesel and 80% petroleum diesel.

If biodiesel is so great, why are we still mostly burning petroleum diesel in diesel engines?

There are a number of reasons. Cost is perhaps the major one, but biodiesel does have some disadvantages. See *Background Information*.

Are there filling stations that sell biodiesel?

Yes. There are dozens of public pumps in many states, and more are coming online almost every week. You can see a map of pump locations at:
http://www.biodiesel.org/buyingbiodiesel/retailfuelingsites/default.shtm

Can I use biodiesel fuel in a regular car in place of gasoline?

No.

Websites for Additional Information and Ideas

A good general Website for information on biodiesel that contains a large number of useful links is the official site of the National Biodiesel Board. It can be found at:
http://www.biodiesel.org/resources/biodiesel_basics/default.shtm

A nice Website listing the properties of various hydrocarbons and their most common uses is at:
http://www.obio.com/hydrocarbon%20chains.htm

Another good general Website that also shows the general kind of reaction that produces biodiesel and also discusses the actual production process is at:
http://www.esru.strath.ac.uk/EandE/Web_sites/02-03/biofuels/what_biodiesel.htm

Some other good general sites:
http://en.wikipedia.org/wiki/Biodiesel
http://www.monsanto.co.uk/biofuels/071202.html