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Biodiesel:
A Cleaner, Greener Fuel for the 21st Century

THOSE OF US WHO DRIVE DIESEL vehicles or heat our homes and businesses with heating oil enjoy the savings this fuel provides—I've driven over 800 miles (1,300 km) on a single tank of diesel fuel in my Volkswagen Passat TDI station wagon—but some of us are not so thrilled about the pollutants emitted by that fuel. Diesel fuel and heating oil emit high levels of sulfur oxides, carbon monoxide, nitrous oxides, hydrocarbons, particulates, and—like all fossil fuels—carbon dioxide. We'd like to do better.

We can do better—with biodiesel. This article examines biodiesel: what it is, where it comes from, its environmental advantages, and where (and how) to use it. We will focus on three primary applications for biodiesel: (1) as a fuel for personal or company-owned vehicles; (2) as a fuel for off-road commercial construction equipment (bulldozers, compressors, cranes, etc.); and (3) as a substitute for heating oil in homes and commercial buildings. While few *EBN* readers will have the opportunity to use biodiesel for all three applications, the first two apply, at least indirectly, to virtually all construction.

What is Biodiesel?

Biodiesel is a diesel-like fuel derived from vegetable oil or other renewable sources. It can be made from soy or canola oil, waste cooking oil, even animal fats. Technically, biodiesel is a *fatty acid methyl ester*. When derived from soy oil (the most common feedstock in the U.S.), biodiesel is sometimes referred to as soy methyl-ester. It is made by combining the vegetable oil with alcohol (usually methanol but occasionally ethanol) in the presence of a catalyst through a process called *transesterification*.

To understand this process, let's consider some simple organic chemistry: Vegetable oil is a *triglyceride*. A triglyceride molecule consists of three fatty acid molecules bound to a glycerin molecule. The process of transesterification breaks off the glycerin and attaches each fatty acid to an alcohol molecule. The first step involves breaking (or cracking) the ester-glycerin bonds. A catalyst is needed for this step—either sodium hydroxide (NaOH) or potassium hydroxide (KOH), both of which are also known as lye, can be used.

(continued on page 2)

Photos: Jock Montgomery and Chewonki Foundation (inset)

The Chewonki Foundation's Center for Environmental Education, designed by Theodore & Theodore Architects in Wiscasset, Maine, is heated with biodiesel produced on-site by Peter Arnold (inset).

In This Issue:

Quote of the month:

"Our school district is willing to spend that extra money to get a cleaner fuel that will expose our children to less pollution."

Bob Cerio, of the Warwick, Rhode Island School District, on the use of biodiesel

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When this reaction is carried out in the presence of alcohol, each of the freed fatty acids bonds with an alcohol molecule.

Note that biodiesel is very different chemically from straight vegetable oil, which some people are also using as a substitute for diesel fuel. "Grease car" conversions involve modifying a diesel vehicle with a second, heated fuel tank. If heated, straight vegetable oil or filtered used cooking oil can be used in diesel vehicles. This article does not cover this type of fuel.

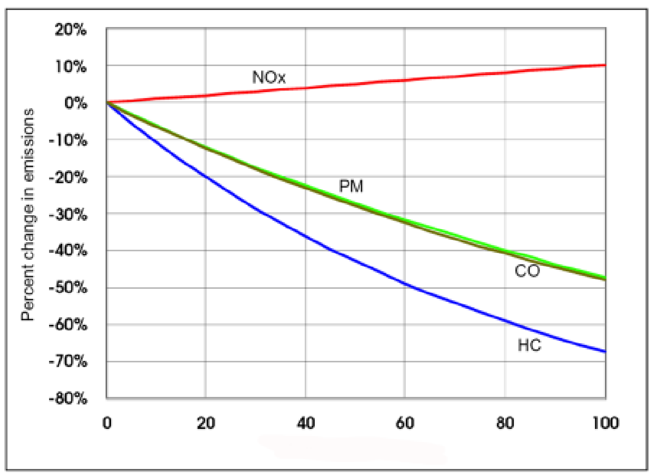
The chemistry involved in producing biodiesel is simple enough that hundreds of renewable energy advocates around the country are making their own using very simple, crude reacting vessels in their garages or basements. The book *From the Fryer to the Fuel Tank*, by Joshua Tickell, provides recipes and procedures for making biodiesel from used cooking oil, often available free from restaurants. Some of the more industrious backyard biodiesel producers are even making soap out of the glycerin that is precipitated out as a by-product.

Biodiesel derived from waste cooking oil is arguably the greenest liquid fuel available because the primary ingredient is a post-consumer waste product. Most biodiesel today, however, is "virgin biodiesel" produced from soy or canola crops. Both recycled-cooking-oil biodiesel and virgin biodiesel are being produced to meet ASTM standard D 6751, approved in December 2001. This new standard, in the works since 1994 by the ASTM Biodiesel Standards Task Force, for the first time provides a consistent biodiesel standard, allowing manufacturers to design (and warrant) equipment with biodiesel use in mind.

It may take a while before engine manufacturers are comfortable with the use of biodiesel. Currently, Ford, Dodge, and Volkswagen all void warranties if biodiesel is used. Volkswagen, however, sells a "biodiesel kit" that includes a few modifications suggested if biodiesel is being used.

Biodiesel has a somewhat lower energy density than petroleum diesel (123,000 vs. 140,000 Btu/gal; 34,000 vs. 39,000 kJ/l). Biodiesel also has more oxygen (10–12% by weight) and a slightly higher cetane number than petroleum diesel.

Average emission impacts of biodiesel for heavy-duty highway engines



As the percentage of biodiesel burned in a vehicle goes up, the emissions of particulate matter (PM), unburned hydrocarbons (HC), and carbon monoxide (CO) go down. Nitrous oxide (NOx) emissions are slightly higher with biodiesel in vehicles. Source: U.S. EPA

Most biodiesel today is mixed with petroleum diesel. The most common mixture is B20, a mix of 20% biodiesel and 80% petroleum diesel. B100, or 100% biodiesel (sometimes called "neat" biodiesel) is being used very successfully by some but is not as widely recommended or used, due to concerns about cold-weather performance, equipment compatibility, and cost (more on these issues below).

Benefits of Biodiesel

Biodiesel is cleaner than petroleum diesel, results in far lower greenhouse gas emissions, is biodegradable, and offers the potential to reduce our dependence on imported oil. Indeed, given such a significant collection of advantages, it is remarkable that this fuel has received so little attention over the years—by the environmental community, by energy policy experts concerned about oil dependence on the Middle East, and by the green building community (including the LEED™ Rating System). Let's take a look at these benefits:

Reduced pollution emissions

Biodiesel is significantly cleaner than petroleum diesel—in almost every pollutant category. Emissions from biodiesel and petroleum diesel combustion are compared below for particulates, unburned hydrocarbons, carbon monoxide, nitrous oxides, sulfur oxides, and polycyclic aromatic hydrocarbons.

Particulates: Particulate emissions from petroleum diesel result in most of the visible "smoke" from diesel vehicles and heavy equipment. Recent studies have shown particulates to be a greater health problem than previously believed. A draft technical report on biodiesel emissions released in October 2002 by the U.S. Environmental Protection Agency (EPA), in which dozens of technical emission studies were examined and statistically compiled, shows an average 47% reduction in particulate emissions by using 100% biodiesel (B100) in place of petroleum diesel. With B20 biodiesel, a 12% reduction in particulate emissions was found.

Unburned hydrocarbons: Unburned hydrocarbons are significant contributors to ground-level ozone pollution and smog. Using B100 biodiesel results in an average 67% reduction of total unburned hydrocarbon emissions; B20 use results in a 20% reduction.

Carbon monoxide: Along with unburned hydrocarbons, carbon monoxide (CO) contributes to ground-level ozone pollution and smog. It is also poisonous and, even at low concentrations, is believed to contribute to various chronic health problems. Using 100% biodiesel in place of petroleum diesel reduces CO emissions by 48%. Using a B20 mix reduces CO emissions by 12%.

Carcinogenic compounds: Petroleum diesel is a significant producer of polycyclic aromatic hydrocarbons (PAH) and nitrated polycyclic aromatic hydrocarbons (nPAH). Compounds in this broad group, which includes various benzene-containing compounds, have been identified as potential carcinogens. A study conducted for the National Biodiesel Board by researchers at the Southwest Research Institute in San Antonio, Texas found reductions in PAH compounds of 48–75% with B100 and 12–60% with B20 compared with petroleum diesel. Reductions in nPAH compounds were even greater: 69–93% with B100 and 13–49% with B20. While the results are limited and point to the need for additional studies, indications are that biodiesel, used alone or in mixtures with petroleum diesel, results in significant reductions in carcinogens.

Nitrous oxides: Nitrous oxide (NOx) is the one emission category where biodiesel may result in higher emissions when compared to petroleum diesel, at least when used as a transportation fuel. NOx emissions are influenced by fuel properties as well as how combustion occurs. (The nitrogen is derived from combustion air, which is close to 80% nitrogen.) In diesel engines, NOx levels increased 2% with a B20 mix and 10% with B100, in the EPA study mentioned above.

Interestingly, studies conducted on biodiesel as a substitute for *heating oil* showed a *decrease* in NOx emissions. Brookhaven National Laboratory scientist C. R. Krishna, in an informational report "Biodiesel Blends in Space Heating Equipment" (prepared for the National Renewable Energy Laboratory), reported NOx reductions in both residential and commercial boilers. While the NOx levels vary according to the oxygen levels at which measurements were taken, reductions for residential boilers averaged about 3% with a B20 mix and 7% with B100. In the commercial boiler tested, NOx reductions averaged about 6% with B20 and 35% with B100. Krishna cautioned that NOx testing has been quite limited to date and that additional investigations are needed, but he told *EBN* that the NOx reductions were "consistently found" in their investigations of biodiesel combustion.

Photo: Brookhaven National Laboratory

Residential boiler being tested with biodiesel fuel at Brookhaven National Laboratory.

Sulfur oxides: Because biodiesel contains extremely low amounts of sulfur (typically 2 to 11 parts per million or ppm), tailpipe emissions of sulfur oxides (SOx) are essentially eliminated. Petroleum diesel used as an on-road transportation fuel has a federally mandated limit of 500 ppm or 0.05% sulfur. This sulfur limit is scheduled to drop to 15 ppm (essentially no sulfur) in 2006. Off-road diesel fuel and #2 heating oil are not regulated as strictly, and sulfur concentrations are typically in the range of 2,000 to 3,000 ppm (0.2–0.3%). This means that when biodiesel is substituted for off-road diesel or #2 heating oil, the benefit of reduced SOx emissions will be even greater than is the case with on-road use.

Reduced odor

Along with the measurable reductions in pollutant emissions, burning biodiesel also reduces the offensive odor associated with diesel or heating oil combustion. Sulfur is responsible for much of the odor problems with diesel, so with no sulfur, biodiesel has a much more pleasant odor. With 100% biodiesel, the emissions have more of a cooking smell than what we associate with diesel vehicles or heating oil.

Positive energy balance

A very important question with any alternative fuel is how much energy it takes to produce and transport it. Ethanol, for example, has been criticized by some because it takes almost as much energy to produce as is contained in the end-product fuel. Dr. David Pimentel, a researcher at Cornell University, published a study in 2001 showing a *net loss* of over 33,000 Btus for every gallon of ethanol produced (9,200 kJ per liter), though a study by the U.S. Department of Agriculture (USDA), published in 2002, shows a net energy gain with ethanol of 21,100 Btu per gallon (5,900 kJ/l), or 34%. Accepting the most recent USDA data, for every unit of fossil-fuel energy used in ethanol production, 1.34 units of ethanol are produced.

With virgin biodiesel made from soybeans, the energy balance is far better. A 1998 report sponsored by the U.S. Department of Energy (DOE) and USDA with technical contributions from the life-cycle assessment (LCA) firm Ecobalance, Inc., "An Overview of Biodiesel and Petroleum Diesel Life Cycles," examined cradle-to-grave impacts of these two fuels for powering urban buses.

This study found that for every unit of fossil-fuel energy consumed in biodiesel production, 3.2 units of biodiesel are produced. On a percentage basis, the net energy gain with biodiesel is 220%. Petroleum fuels have a negative energy balance (a net energy loss) because it takes energy to extract, process, and transport that fuel. Gasoline, petroleum diesel, ethanol, and biodiesel are compared in the table below.

Energy Balance of Various Fuels

Fuel Type	Energy Balance	Net Energy Gain (or Loss)
Gasoline [1]	0.74	(26%)
Petroleum diesel [1]	0.83	(17%)
Ethanol [2]	1.34	34%
20% biodiesel blend (B20) [3]	0.98	(2%)
100% biodiesel (B100) [3]	3.20	220%

Sources:
1. "Energy Balance/Life Cycle Inventory for Ethanol, Biodiesel and Petroleum Fuels," Minnesota Department of Agriculture, www.mda.state.mn.us/ethanol/balance.html.
2. "The Energy Balance of Corn Ethanol: An Update," U.S. Department of Energy, July 2002.
3. "An Overview of Biodiesel and Petroleum Diesel Life Cycles," National Renewable Energy Laboratory, May 1998.

Note that the energy balance of biodiesel will be even better with a state-of-the-art plant, such as a newly completed facility built by West Central Soy in Ralston, Iowa. According to production manager Myron Danzer, this plant uses a continuous (rather than batch) process and recovers for reuse both process water and methanol. The plant achieves a 7:1 energy balance within the plant. (They don't have energy data for the entire life cycle.) Producing biodiesel from waste cooking oil most likely achieves the highest energy balance of all, because the raw material is a waste product, so the only energy input for the vegetable oil component is in getting it to the processing facility.

Reduced greenhouse gas emissions

Closely related to the energy balance numbers, significant reductions in greenhouse gas emissions result from the use of biodiesel. While combustion of any biofuel releases carbon dioxide into the atmosphere, growing the agricultural crop used in that fuel captures a similar amount of CO_2 through the process of photosynthesis. With diesel engines, emissions are typically reported relative to brake-horsepower-hour units of engine work. The DOE/USDA life-cycle study found the net CO_2 emission from petroleum diesel to be 633 grams of CO_2 per brake-horsepower-hour (g/bhp-h), while the net CO_2 emissions for B100 biodiesel are 136 g/bhp-h, a 78% reduction (in metric, 849 vs. 182 g/kWh). With a B20 mix, the net CO_2 emissions are 534 g/bhp-h (716 g/kWh), a 16% reduction from the petroleum diesel emissions.

Biodegradability and solid waste

Biodiesel is fully biodegradable, so spills are much less of a problem than with petroleum diesel. A 1993 Austrian study found that 98% of biodiesel biodegrades in three weeks. This benefit has made biodiesel a particularly attractive fuel in significant natural areas (it is being used in several national parks) and in marine applications.

The benefit of biodegradability became very clear on August 29, 2001, when a rail car carrying 28,000 gallons (106,000 l) of B100 biodiesel derailed in Arizona. The initial reaction of the Arizona Department of Environmental Quality and local emergency officials was panic, as they prepared to deal with what they assumed was a toxic diesel spill. When they discovered that it was *biodiesel*, those concerns were greatly allayed, and cleanup was accomplished quickly and easily.

The DOE/USDA life-cycle study compared hazardous and nonhazardous waste generation of petroleum diesel and biodiesel over their respective life cycles. B100 biodiesel results in 96% less hazardous waste than petroleum diesel—0.018 vs. 0.41 g/bhp-hr (0.024 vs. 0.55 g/kWh). Seventy percent of the hazardous waste from the biodiesel life cycle comes from soybean agriculture, but this is due primarily to petroleum diesel and gasoline used in farming operations. Biodiesel does cause more *nonhazardous* waste than petroleum diesel, however—most of which results from the soybean crushing stage of the life cycle.

Increased engine or burner life

Biodiesel has better lubricating properties than petroleum diesel. As a result, it may increase engine life and reduce wear and tear on burners in oil-fired boilers and furnaces. Good data on these benefits is not likely to be available for several years, however, because of the very long operating life of even conventional diesel engines and oil burners.

Reduced foreign oil dependence

While not strictly an *environmental* benefit, the use of domestically produced biofuel can reduce U.S. reliance on imported oil. The Bush Administration has shown considerable interest in biofuels in an effort to attain greater energy self-sufficiency, though most research funding and financial incentives to date have been for corn-derived ethanol—a biofuel with a rather poor energy balance.

Resource Considerations with Biodiesel

Let's take a look at how much distillate fuel oil we consume. This is the fuel (diesel fuel and heating oil) that could be replaced with biodiesel. Current annual U.S. consumption of distillate fuel oil totals about 59 billion gallons (2.2×10^{11} l), according to DOE. On-road diesel accounts for the largest share of this at 56%. Combined residential and commercial fuel oil consumption account for 16.6% of the total. These and other primary uses of distillate fuel oil are shown in the table on page 5.

Just how much of the distillate fuel

oil market could eventually be satisfied by biodiesel is hotly debated. The National Biodiesel Board, a ten-year-old organization promoting the use of biodiesel, says the current U.S. production capacity for biodiesel is about 200 million gallons (760 million l) per year. According to Dr. Shaine Tyson, who manages biodiesel research at NREL, the Department of Energy projects that U.S. production of biodiesel could climb to 2.5 billion gallons (9.5×10^9 l) per year by 2020, while total ethanol production could climb to over 6 billion gallons (2.3×10^{10} l) per year. (This difference may account for the disparity in federal funding for biodiesel vs. ethanol—far more funding currently goes into ethanol.)

Many biodiesel proponents argue that biodiesel production and use could grow far more dramatically. The simplicity of biodiesel production means that plants can be built quickly and inexpensively, offering potential to rapidly scale up production. The National Biodiesel Board says that the current biodiesel production capacity could be tripled in one year. To better understand potential production of biodiesel, let's take a more detailed look at the raw materials.

As noted above, biodiesel can be derived from agricultural crops as well as from waste cooking oil and animal fats. From an environmental standpoint, producing biodiesel from waste oils and fats is a more environmentally attractive option, because the raw material is a post-consumer waste product.

These biodiesel feedstocks include yellow grease (used cooking oil), inedible tallow (by-product of meat production), and trap grease (a waste product collected from sewage traps under kitchen drains). In 2001, according to Dr. Tyson, 219 million gallons (830 million l) of yellow grease and 258 million gallons (975 million l) of inedible tallow were produced but not consumed for other uses (i.e., these quantities would have been available for biodiesel production). In the same year, 495 million gallons (1.9×10^9 l) of trap grease were produced, which could also be used in biodiesel production, though the high percentage of free fatty acids makes conversion into methyl esters more difficult.

A gallon (3.8 l) of yellow grease or fat produces just under a gallon of biodiesel (after adding methanol and precipitating out glycerin). Therefore, a theoretical maximum of just under a billion gallons (3.7×10^9 l) of biodiesel could be produced annually from these waste oils and fats if the infrastructure were created to collect and process them. Currently, much of the biodiesel produced from used cooking oil is made by backyard producers and not reported. Just 5–10% of the biodiesel sold by World Energy is derived from waste oils and fats, according to the company.

U.S. Sales of Distillate Fuel Oil by Category - 2001

Energy Use	Million Gallons	Million Liters	% of Total
Residential	6,263	23,710	11%
Commercial	3,505	13,268	6%
Industrial	2,324	8,797	4%
Farm	3,427	12,974	6%
Electric Power	1,510	5,717	3%
Railroad	2,952	11,174	5%
Marine	2,093	7,924	4%
On-highway Diesel	33,215	125,733	56%
Off-highway Diesel	2,515	9,519	4%
Military	346	1,310	1%
Other	820	3,105	1%
TOTALS	58,971	223,231	100%

Source: U.S. DOE Energy Information Administration

Virgin biodiesel in the U.S. (nearly all of which is from soybeans) is produced in 18 dedicated biodiesel plants located in farming regions as well as in a number of glycerin plants—which produce methyl ester as a by-product. The newest dedicated plant, completed in December 2002 in Ralston, Iowa, has an annual capacity of 12 million gallons (45 million l).

Some argue that using food crops such as soybeans for fuel production is wrong. Such crops should be used for food, especially since there are nearly a billion malnourished people in the world. There is certain validity to this reasoning, but an argument can also be made that as long as prime agricultural land in the U.S. is being lost to development because farmers can not make a living farming, there is a benefit to creating new markets for agricultural products.

Furthermore, other agricultural crops can produce far more vegetable oil per acre than soybeans. A number of oil crops are listed in the table on page 6, including one that can produce more than ten times as much oil per acre as soybeans. Ideally, we should consider the sustainability of crop production. Some crops can be grown with fewer chemical inputs than others. Organic farming practices are preferable.

In the long run, it may even be possible to produce oil from such crops as yeast, molds, and algae. Scientists at NREL investigated algae as an oil crop from the late '70s through the mid-'90s but have discontinued this work. Some research is continuing in this area.

Biodiesel Applications

Our discussion here will focus on three application areas: transportation, commercial construction equipment, and space heating.

Biodiesel as transportation fuel

Biodiesel can substitute for petroleum diesel in any vehicle designed to operate on diesel fuel. In fact, when Dr. Rudolf Diesel first developed the diesel engine in 1895, he intended that it would be operated on vegetable oils in addition to distillate oil. At the 1900 World Exhibition in Paris, Dr. Diesel demonstrated his new engine using peanut oil, and in

1912 he said, portentously, that "the use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in the course of time as important as petroleum and the coal tar products of the present time."

Among auto manufacturers, only Volkswagen currently markets diesel cars in the U.S., though in Europe, diesels account for about 40% of the passenger car fleet. There are more diesel options with light trucks and sport utility vehicles (SUVs), where buyers appreciate the towing power, durability, and (relative) fuel economy of diesel engines. Unlike the underpowered, noisy, smelly, and polluting diesels that were sold in the U.S. during the 1970s and '80s, most diesel cars and light trucks sold today rely on turbo direct-injection (TDI) technology, which offers greater power and acceleration, reduced emissions, and improved fuel economy. (TDI engines are still a lot noisier than gasoline engines, and the exhaust is smelly.)

Biodiesel can be used in diesel cars, light trucks, and heavy trucks with few or no modifications. Studies show that a 20% blend of biodiesel (B20) can be burned in any diesel engine with absolutely no modifications and with almost no restrictions. At a higher concentration, the more aggressive solvents in biodiesel may degrade certain rubber parts. Biodiesel experts recommend replacing certain hoses, for example, with fluoroelastomer products, such as Viton®, that resist degradation from the biodiesel.

Be aware that because biodiesel is a better solvent than petroleum diesel, use of biodiesel is likely to dissolve crud that's been accumulating in the fuel tank. As a result, the fuel filter will probably need to be replaced shortly after making the switch.

The most significant limitation of biodiesel as a transportation fuel is its cold-weather performance. Biodiesel can gel at temperatures below 32°F (0°C) and must be mixed with petroleum diesel, kerosene, or special additives in cold weather. For this reason (and due to cost), most users of biodiesel as a transportation fuel use a relatively modest B20 blend—this is what I am using in the winter in my VW Passat. According to Dr. Tyson at NREL, gelling problems were experienced with a B35 blend (35% biodiesel) several years ago in Ralston, Iowa. "We've seen no problems with B20," she told *EBN*. Currently, more than 200 vehicle fleets nationwide are operating on a biodiesel blend—most with B20, some with even lower biodiesel percentages (B10 or B5).

Rockland Materials in Phoenix, Arizona operates its entire fleet of ready-mix concrete trucks and other equipment with B100 biodiesel. Photo: Rockland Materials

In warmer climates, however, and during the warmer months in northern climates, some users are having great success with B100. Rockland Materials, Inc., in Phoenix, Arizona has been operating its entire fleet of trucks, as well as various other pieces of machinery, on B100 biodiesel for about two years. Growing quickly, the company now has about 120 on-road vehicles (mostly ready-mix concrete trucks) operating without any problems on biodiesel. Grant Goodman, owner of the company, estimates that his trucks have now driven close to a million miles on biodiesel. "We've had no problems whatsoever," he reports. They didn't make any modifications to the truck engines or fuel systems; they simply started using biodiesel.

In fact, using biodiesel may even extend the life of diesel engines, due to the superior lubricating properties of biodiesel. In Goodman's case, it's still too early to tell—a typical diesel engine lasts 7–15 years—but "all indication is that it will extend the engine life," he said.

Using biodiesel instead of petroleum diesel is costing Rockland Materials roughly $200,000 to $300,000 extra per year. When asked how be can justify that cost economically, he said he can't. "It's just the right thing to do," he told *EBN*. Goodman's wife and son both suffer from asthma, which was an important motivation for doing something about air quality. In the January 1, 2002 issue of *Soybean Digest*, Goodman was quoted as saying, "It would nauseate me if I were running all these trucks and knew I could do something about

Productivity of Various Oil Crops [1]

Oil Crop	Scientific Name	Oil Production lb/acre (kg/ha)
Corn	*Zea mays*	135 (145)
Hemp	*Cannabis sativa*	280 (305)
Soybean	*Glycine max*	345 (375)
Safflower	*Carthamus tinctorius*	605 (655)
Sunflower	*Helianthus annuus*	720 (800)
Peanut	*Arachis hypogaea*	815 (890)
Rapeseed and canola	*Brassica napus*	915 (1,000)
Coconut	*Cocos nucifera*	2,070 (2,260)
Oil palm	*Elaeus guineensis*	4,585 (5,000)

1. Based on international averages

Source: *From the Fryer to the Fuel Tank* by Joshua Tickell, 2000 our air quality and didn't. In trucking, we have a huge opportunity to impact the environment positively if we choose to do so."

Biodiesel as off-road fuel for heavy equipment

While significant environmental advantages can be realized by operating highway vehicles on biodiesel, the benefits can be even greater with off-road diesel equipment. As noted previously, off-road diesel fuel does not have to meet federal low-sulfur standards (500 ppm), and sulfur levels of 2,000–3,000 ppm are typical. Off-road, high-sulfur petroleum diesel is widely used on thousands of job sites in everything from bulldozers and excavators to cranes and compressors. For this equipment, switching to biodiesel can provide a huge environmental benefit.

Rockland Materials has been operating loaders, excavators, rock-crushers, mining equipment, and generators (gen-sets) on B100 without incident as long as it's been operating trucks on the fuel. Using biodiesel has not affected equipment warranties, either. "We have the blessings from Caterpillar and Cummins to do that," said Goodman.

On a far smaller scale, the design-build firm, South Mountain Company on Martha's Vineyard has been using biodiesel in the forklifts they use for moving lumber and timbers in the salvaged wood yard. Because of the small quantities of biodiesel used and the lack of a local supplier, they buy biodiesel by the 55-gallon (210-liter) drum (see page 9).

Biodiesel as heating fuel

Heating oil is a regional fuel used predominantly in the Northeast (80% of residential heating oil and 49% of commercial heating oil is consumed in the six New England states plus New York, New Jersey, Pennsylvania, and Maryland). Most of this is high-sulfur-content distillate oil, with sulfur content of 2,000 to 3,000 ppm. These applications are prime candidates for substitution of a biodiesel blend.

These boilers in the Warwick School District are operating very successfully with a B20 biodiesel blend. Photo: Bob Cerio

Because heating oil is used primarily during the winter months, delivery and storage are significant concerns with biodiesel. The higher the biodiesel fraction, the higher the temperature at which gelling will occur. This characteristic of fuel oil is referred to as the "pour point" (the temperature below which the fuel will not pour). The pour point for standard #2 petroleum fuel oil is -11°F (-24°C). For B20 biodiesel, the pour point is 0°F (-18°C), and for 100% biodiesel (B100), the pour point is 32°F (0°C). Biodiesel should be stored at a temperature well above its pour point. For B100, this will mean storage indoors in a heated space or, depending on the climate and biodiesel mix, in an underground tank. Even B20 may need to be stored underground or indoors in the coldest climates.

The Warwick, Rhode Island School District has been testing various mixes of biodiesel as a heating fuel for the last two heating seasons. During the first year of testing, they ran three different concentrations of biodiesel (B10, B15, and B20), along with a petroleum diesel control. "It worked out very, very well," reports an enthusiastic Bob Cerio, energy manager for the school system. "It's probably the best thing since sliced bread," he told *EBN*. Following a successful first season of biodiesel use, Cerio began using B20 in all of the boilers at the start of the 2002-2003 heating season, and he's had "no problems whatsoever." In one of the schools, there is a bank of seven boilers, each rated at 1.75 gallons per hour (gph) (6.2 liters per hour). (Commercial boilers are typically rated by the fuel flow; 1 gph is equivalent to a firing rate of about 140,000 Btu/hour.) A second school has a bank of four 2.0 gph (7.6 lph) boilers, and a third has a single 18 gph (68 lph) boiler.

The Warwick schools rely on underground tanks, so Cerio says he could probably go to a higher mix of biodiesel, but he is glad to stick with the B20 mix. "I didn't want to take a chance." His testing shows a reduction in all pollutants, including NOx.

Using biodiesel has increased fuel costs for the Warwick School District. The biodiesel is delivered as B100 and mixed in their tanks. Cost of the B100 has ranged from $1.30 to $1.76 per gallon (34–46¢/l). Since they purchase petroleum diesel on long-term contracts for as little as 80¢ per gallon (21¢/l), there is a large differential between the fuel oil and biodiesel cost, but cost of the biodiesel blend has been only moderately more expensive than what some customers pay for standard heating oil. During the first year, when they were paying an average of $1.35 per gallon (35¢/l) for B100, their actual cost premium for the heating oil consumed (at B10, B15, and B20 blends) worked out to be about 5¢/gallon (1.3¢/l). For this heating season, Cerio guesses the cost premium will be about 10¢/gallon (2.6¢/l). So far, the higher price hasn't been an obstacle. "Our school district is willing to spend that extra money to get a cleaner fuel that will expose our children to less pollution," he told *EBN*. Cerio, who is also involved with integrating energy conservation issues into the curriculum at the Warwick schools, notes that energy conservation efforts have saved $2 million in energy costs over the past four years—25%. If the biodiesel use is considered as part of a package of changes implemented, the overall cost savings are still very significant.

The Chewonki Foundation in Wiscasset, Maine has also been using biodiesel as a heating fuel off and on for the past two years, though they have not tracked the exact usage and specific blends. They started out by purchasing commercially produced B100 but began making their own biodiesel from used cooking oil two years ago. Peter Arnold, of the nonprofit environmental education organization, picks up the used cooking oil at area restaurants. He hoists 55-gallon (210-liter) drums into his truck using a small hydraulic barrel hoist mounted in the bed. Back at the Chewonki Foundation, he processes the oil into biodiesel in an old pole barn now known as the Biodiesel Center (see photo). He is currently producing 3,000–5,000 gallons (11,000–19,000 l) of B100 per year.

While most of the biodiesel Arnold produces is used in the Foundation's diesel vehicles, it is also used in their dual 200,000 Btu (1.65 gph, 6.3 lph) Crown boilers. After about nine months of biodiesel use in the boiler, a pump seal failed. When Arnold contacted the pump manufacturer, Suntec, he was told that they were aware of the problem when high concentrations of biodiesel are used and are working to fix the problem. In the meantime, Suntec told him how to have the pump rebuilt using a mechanical seal, and Arnold hasn't had any problems since. He also told *EBN* that his heating technician has needed to do some extra cleaning and deal with some incomplete combustion. "They have done some playing with the nozzles and pressure, thinking that a better spray pattern would help," Arnold said.

Photo: Peter Arnold

The Chewonki Foundation collects used cooking oil from nearby restaurants to make 3,000–5,000 gallons (11,000–19,000 l) of B100 biodiesel annually.

Remarkably, very little testing has been done on biodiesel as a heating fuel. The most comprehensive investigations to date have been conducted by C. R. Krishna at Brookhaven National Laboratory, under contract to first NREL and then the New York State Energy Research and Development Authority (NYSERDA). Tests were conducted both on a residential boiler (with a burner rated at 0.6 gph, 2.3 lph) and a commercial boiler (rated at 8.05 gph, 30.5 lph).

A key purpose of the research, according to Krishna, was to determine what biodiesel blend could be used without modifying the equipment at all. Tests were done with conventional #2 fuel oil, B10, B20, B30, B100, and a 50:50 blend of biodiesel and kerosene (BK50). The basic findings were that a 20–30% blend (B20 or B30) could be used without seeing any difference or having to change to anything. Much higher than that, according to Krishna, might cause problems. These potential problems might include degradation of pump seals and other components that aren't as resistant to the solvents in biodiesel (although Krishna's tests weren't long enough to see these problems), and malfunctioning due to the cadmium sulfide cell (Cad cell). A Cad cell is used as a safety control to shut off fuel flow if the flame goes out; it is optimized for #2 petroleum diesel, which has a yellowish flame. Because B100 biodiesel burns cleaner, the Cad cell may not see the flame and shut off the fuel. Both of these potential problems could be solved easily by manufacturers. Krishna speculated that pure biodiesel might also have problems starting up in very cold weather, although he did not experience this.

The Brookhaven testing also looked at pollution emissions. Carbon monoxide emissions from petroleum diesel, pure biodiesel, and the various blends were fairly similar during ignition (when CO emissions spike), though the peak values were somewhat higher with biodiesel in some of the tests—which Krishna found surprising. After warm-up, the steady-state operation found biodiesel and biodiesel blends to be lower in both CO and NOx emissions. The lower CO levels may be due to higher oxygen levels in biodiesel than petroleum diesel. The cause of the lower NOx levels warrants further investigation, according to Krishna.

NYSERDA is also funding a study in Newburgh, New York in which 100 homes are being heated with B20 biodiesel. Now in its second heating season, the study has so far found no significant problems.

The Frontier Oil Company in South China, Maine is one of the few fuel oil dealers that sells biodiesel. Co-owner Brad Taylor is enthusiastic about biodiesel, and his experiences have been very positive. "So far, we've had great luck with it," he told *EBN*. The demand is pretty good, he reports, but fairly spread out. Frontier Oil buys biodiesel from World Energy but not in large enough quantities to warrant delivery by tractor trailer truck, which can carry 8,000–10,000 gallons (30,000–38,000 l). Instead, they take one of their own 3,000-gallon (11,000-liter) trucks down to Cambridge, Massachusetts to pick up B100 from World Energy rail cars. At press time, Frontier was selling B20 for $1.699 per gallon ($0.448/l) vs. $1.379 per gallon ($0.364/l) for #2 heating oil.

Frontier adds the red dye required for heating oil (so that officials can determine if someone is using tax-exempt heating oil as a highway fuel) and delivers the fuel in a fairly wide region. Most of their biodiesel customers are using it in a B20 mix, but some use B50 or even B100. Taylor says the primary challenges in using the higher concentrations are storage and delivery. Indoor storage is needed, and delivery is restricted in the coldest months. He is comfortable delivering B100 only through late October. Taylor's partner in the business has been using B100 in his home boiler without any problems. Taylor, whose company also does plumbing and heating contracting, doesn't expect to see many problems with heating equipment burning biodiesel. "The only potential for any kind of problem," he told *EBN*, "is the shaft seal on some pumps. The stuff burns really clean."

Taylor suggests that until biodiesel takes off, it is likely that only the small, independent fuel oil dealers (like his own) will be interested in carrying it. He notes that because B100 is an agricultural product, it can be stored in fairly inexpensive plastic tanks; double-lined tanks are not required, as they are for petroleum diesel, but indoor storage is necessary.

Final Thoughts

While attracting very little attention from environmentalists or the green building community, biodiesel is here today as an option for significantly reducing the impacts of construction and, at least in the Northeast, the impacts of heating buildings. Those willing to get involved in their fuel production can consider doing what the Chewonki Foundation is doing by collecting and processing their own biodiesel fuel. While potentially saving money, this is a labor-intensive process that most end-users won't want to undertake.

Others can purchase commercially available biodiesel and mix it with petroleum diesel as appropriate for the climate and application. While this may be one of the best options for reducing greenhouse gas emissions from construction and (in the Northeast) heating buildings, it is not without obstacles. The first obstacle is cost. Commercially available biodiesel is more expensive than petroleum diesel or #2 heating oil. That could change, of course, if a war in Iraq or lingering strikes in Venezuela cause crude oil prices to continue rising. But it is likely that if petroleum prices rise, biodiesel prices will follow suit—as occurs with other energy commodities.

The second obstacle, as I have learned in trying to heat my home and operate my car on biodiesel, is the lack of local suppliers of either B100 or B20. Since summer, several friends and I have been trying to organize a biodiesel buying cooperative in the Brattleboro area, but protected storage has been a problem. This ties back into the cost obstacle. World Energy, the nation's largest distributor and retailer of biodiesel (with about 75% of the market), will deliver biodiesel in bulk to us, but until we can figure out a way to purchase that fuel in large enough quantities, the delivery cost will remain a very large percentage of the per-gallon fuel cost. World Energy will ship B100 biodiesel to any location in the country in 55-gallon (210-liter) drums for the applicable per-gallon charge plus a flat shipping fee of about $90, but that arrangement adds close to $2 per gallon (53¢/l) for shipping. With bulk deliveries to southeastern Vermont, there is a delivery fee of about $600. If ordering 1,000 gallons (3,800 l), the delivery adds 60¢/gallon (16¢/l), while delivery of a 3,000-gallon (11,000 l) order costs only 20¢/gallon (5¢/l)—a much more reasonable surcharge.

The biodiesel that World Energy sells for highway use has highway taxes built into the price; that tax does not need to be levied on biodiesel sold as a heating fuel. But what about a user like me who wants to use biodiesel in both my car and home? I would have to buy two types of biodiesel, which further complicates my ordering and storage (and potentially increases costs). (The Senate version of the energy bill that stalled last year included a provision to reduce the federal excise tax on biodiesel to the tune of 1¢ for each percent-biodiesel up to 20%, so that the tax on B20 would be reduced by 20¢/gallon [5¢/l].)

For biodiesel to really catch on, more users will have to venture out alone, as Rockland Materials is so admirably doing in Phoenix. Once demand increases, suppliers will greatly improve the convenience of using this fuel. Meanwhile, more research is needed on the operational issues related to the use of biodiesel, especially as a heating fuel, and manufacturers should be encouraged to modify their equipment so that it can operate on pure biodiesel.

– Alex Wilson

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From the Fryer to the Fuel Tank: The Complete Guide to Using Vegetable Oil as an Alternative Fuel by Joshua Tickell, published by Tickell Energy Consultants, Covington, LA

U.S. Environmental Protection Agency
Office of Transportation and Air Quality
www.epa.gov/OMS/models/biodsl.htm

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