

Biobased Lubricants: Gearing up for a green world

The technical and political barriers that once slowed the use of bio-lubes in the U.S. and Europe are steadily being solved.

KEY CONCEPTS

- The advantages of biobased lubricants include biodegradability, superior lubricity, higher flash/fire points, high VI, basestock renewability and domestic agricultural support.
- Disadvantages include poor oxidative stability and poor low-temperature performance.
- The future of biobased lubricants depends on overcoming the disadvantages while being price competitive with mineral-based and synthetic lubricants.

At 10:45 a.m. on Jan. 28, 1969, Union Oil workers were trying to pull the drilling tube out of an ocean well near Santa Barbara, Calif. Even though the tube was obviously stuck, they kept pulling. Suddenly gas and dirt from 3,000 feet below the waterline spewed violently into the air, splattering everything and everyone with grease.

The workers somehow managed to plug the well but not the oil and gas leak. In fact, the sea was actually bubbling as far as 800 feet away from the platform because the oil pressure had slashed five long tears through the ocean floor. Before the leak was completely stopped, more than three million gallons of crude oil flooded into the environment.

For weeks afterward, birds rendered flightless by the oil slowly died on the beaches. The waves were so thick with oil that they broke on shore without making a sound. Thirty miles of pristine beaches were contaminated with thick sludge, and hundreds of ocean miles were topped with an ugly rainbow black sheen. And all of this was on the national news.

As horrific as this accident was, not all of the consequences were dire. In the aftermath of the disaster, the environmental movement and the concept of biodegradability were born.

The generally accepted definition of biobased lubricants is that they're formulated with renewable and biodegradable basestocks.

In the decades that followed, researchers hoping to bring biodegradable products to market encountered a number of hurdles—significantly performance and price. The same issues persist with biobased lubricants.

The good news is that biobased lubricant researchers are beginning to resolve performance problems in a way that's cost competitive with mineral-based and synthetic lubricants.

BACKGROUND

The University of Northern Iowa Ag-Based Industrial Lubricants Research Center (UNI-NABL) has licensed 30 formulated lubricants, greases and base oils made from high oleic (genetically modified) soybeans.

Products currently available from soybean oils include:

- Tractor transmission hydraulic fluid
- Industrial hydraulic fluids for process and machinery applications
- Metalworking oils and coolants
- Food-grade hydraulic fluids
- Chainsaw bar oil
- Gear lubes
- Compressor oil
- Transformer and transmission line cooling fluids
- Greases including automotive, machinery, rail curve, track and food grade.

Currently biobased lubricants are operational in a limited number of environmentally-sensitive applications such as in transformers, building elevators and machinery used in or near forests, agricultural land and waterways.

BIOBASED DEFINITIONS

There are three types of lubricant basestocks:

- Petroleum or mineral-based (referred to as *mineral-based* here)
- Synthetic
- Biobased—derived from renewable plant or animal sources.

The generally accepted definition of biobased lubricants is that they're formulated with renewable and biodegradable basestocks. It's worth noting that some definitions only consider biodegradability.

To be biobased, lubricants don't have to be composed entirely of unaltered vegetable oil; rather, the base materials just need to be renewable. This means fatty acids qualify, as do natural vegetable oils that are treated to produce a modified product.



Biodegradable soy-based hydraulic fluid has been used to operate the elevator system in the Statue of Liberty since Nov. 14, 2002.

SOYBEANS AND RAPESEEDS

Researchers are currently working with a handful of plants—soybeans, rapeseeds, canola, palm oil trees, sunflowers and safflowers.

In the U.S. soybeans are by far the most widely researched and tested for a number of reasons, most notably that the plants are abundantly available. In Europe, where biobased lubricants are already in widespread use, rapeseed is abundant and the most common basestock. While products formulated from soybeans and rapeseeds are about equal as far as lubricant properties go, soybeans are widely grown for

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human consumption while rapeseed is not, and this creates some issues. Rapeseed has the advantage of producing more oil per unit of land area than many other oil sources.

Canola is a rapeseed hybrid that was initially created in Canada. Canola—the word is a hybrid of Canadian *oilseed*, *low acid*—was used by the Manitoba government to label the seed during its experimental stages and is now a trademarked name for rapeseed with low levels of erucic acid and glucosinolate.

Biobased lubricants have been used in Europe for more than 20 years, mostly because of regulations and mandates that necessitated the use of biodegradables. But despite the long-term use, biobased lubricants represent only about 1% of total European lubricants¹ (see sidebar *The European Market*).

CURRENT STATE

STLE-member Dr. Brajendra Sharma, a visiting research chemist in the Bio-Oil Research Unit of the National Center for Agricultural Utilization Research (NCAUR) operated by USDA's Agricultural Research Service (ARS) in Peoria, Ill., is very encouraged by progress in biobased lubricant research.

"We have already commercialized two successful technologies in our lab," he said "One is a biodegradable soy-based hydraulic fluid that has been used to operate the elevator system in the Statue of Liberty since Nov. 14, 2002. The other technology is soy-based hot rolling lubricants that are being used by a large aluminum manufacturing company (Alcoa) for hot flat-rolling operations. The company produces aluminum sheets for everything from beer cans to aircraft wing panels for hot flat-rolling operations."

The European Market: An interview with Dr. Boris Zhmud

Europe has been leading the biobased lubricant market for 20 years. Experts expect that by 2010 18% of all lubricants used in Europe will be biobased. But not all European biobased lubricants are completely plant-based. Surprisingly, in some countries the bio designation only requires 50% renewable content. This means bio-labeled lubricants can (and some do) contain synthetic esters and petroleum oils.

STLE-member Dr. Boris Zhmud is the research and development manager for E-ION in Brussels, Belgium. Following is a brief interview about the state of biobased lubricants in Europe.

TLT: Why has Europe been so quick to use biobased lubricants?

Zhmud: In Europe the use of biobased products in past decades has been spurred by regulatory mandates. Some previous technical developments carried out during wartime and shortage situations (mostly during the Second World War and the Caribbean oil crisis) also factored into this.



Dr. Boris Zhmud

TLT: What is the status of biobased lubricant use in Europe?

Zhmud: The market for biobased lubricants is driven by a combination of economic factors that include the high price of mineral oil, tax incentives to promote biobased products, the cost of recycling and penalties

applied in case of accidental release. There are also performance requirements and environmental regulations requiring biodegradability and low-toxicity in sensitive areas.

Now biobased products are being successfully applied in metalworking and industrial lubricants, greases, tractor oils and hydraulic fluids. The use of biobased automotive lubricants is so far very limited because of performance issues. However, some biobased products proved to be highly efficient as lubricity additives in formulations of fuel-economy engine oils and transmission fluids.

TLT: Are you using any genetically modified plants for lubricants?

Zhmud: Almost certainly, although there is no official data available. In any case,

the genotype of the biological source does not change the chemical structures of individual molecules—only their relative abundance. Therefore, in my opinion, use of genetically modified plants is a viable option for production of biobased fuels and lubricants.

TLT: What are you working on right now?

Zhmud: We are working on the commercialization of Elektrionized™ vegetable oils as lubricity additives for lubricants. Biobased lubricating and fatty oil-like additives produced by Elektrionization from vegetable feedstocks have unique tribological properties. In combination with modern synthetic and severely hydro-processed mineral-base oils, Elektrionized vegetable oils create a solid foundation for formulating top-quality lubricants.

TLT: Where do you see the European market for biobased lubricants in five years?

Zhmud: As the economy recovers, technology advances and public awareness grows, more benefits of biodegradable lubes and greases will be recognized, and the market will see more biobased products.

1. Source: Rolf Luther of Fuchs Oil, Europe. As reported in *Bio-Based Lubricants – A Market Opportunity Study Update*, United Soybean Board, Nov. 2008.



Dr. Brajendra Sharma, senior research associate at Penn State University, uses a standard four-ball test method to measure friction and wear properties of vegetable oil-based lubricants.

In tests, the soy-based hydraulic fluid worked as well as or better than the mineral oil products, particularly in terms of lubricity, biodegradability and reduced flammability.^{2,3}

Also at Penn State University, STLE-member Dr. Joseph Perez, senior research scientist for the chemical engineering department's tribology group, has been implementing and overseeing the use of biobased lubricants and biofuels in the university's farm equipment since 2003.

In 2003, the university converted all 200 pieces of farm equipment to make them compatible with biodegradable hydraulic fluids. The fluid is a TMP or PE-type base fluid made from vegetable oil. The same vehicles also have been running on biodiesel fuel since 2003. The university, which generates about 20,000 gallons of waste cooking oil a year, is in the process of making its own biodiesel fuel from waste cooking oil.

"The lubricant in use has better oxidation stability than soybean or canola oils," Perez says. "The equipment has been running on one version since 2003 without any problems. The bio-lubricants are as good as or better than the petroleum products we were using prior to that. We do a lot of testing to ensure equivalent performance."

Perez added that they actually saw a reduction of operating temperatures in hydraulic fluid systems in some pieces of equipment.

"All of our farm equipment people like the biodiesel fuel because it reduces emissions," Perez says, "and since we're using waste cooking oil as our basestock, a side benefit is that it smells great."

Two years ago, Perez and his team assisted a vegetable

oil company, Bunge North America, in modifying an existing soy-based hydraulic fluid to meet state groundwater requirements. This allowed the university to use biodegradable hydraulic fluids in some 35 campus elevators.

Penn State is typical of a number of institutions in the U.S. that are actively looking for ways to green their facilities, services and products. But it's a balancing act between the advantages and disadvantages of biobased products.

BUILDING ON ADVANTAGES

The most obvious advantage of biobased lubricants is biodegradability, but there are several others that allow these lubricants to compete with or exceed the standards set by mineral-based and synthetic lubricants.

Less toxic. About 50% of all used oil ends up in the environment. Mineral-based and synthetic lubricants don't degrade well, creating an environmental liability.

Biobased is not the same as biodegradable. Just because something is biobased does not necessarily mean it's biodegradable. Nearly all biobased lubricants *are* biodegradable—meaning microorganisms can break them down into innocuous carbon dioxide. In the case of a spill, non-toxic and biodegradable biobased lubricants require less remediation and create less damage. All of this also applies to biobased lubricants made from conventional or genetically modified crops, but most of this does not apply to lubricants that contain non-biobased components.

Spill remediation. Another benefit is the significantly lower cost for spill remediation. For example, the Pennsylvania Department of Environmental Protection (DEP) requires complete cleanup of

all oil spills. Since Penn State has a large agricultural department, they have more than 3,000 acres of farmland to maintain. And since they regularly perform research on that land, they were spending a lot of money to clean up hydraulic oil spills.

According to Perez, "Now we can basically just dig it up and put it in a landfill. We are spending far less money on remediation."

Superior lubricity. Biobased lubricants have a higher lubricity and therefore a much lower coefficient of friction compared to mineral-based lubricants. Enhanced lubricity reduces friction and wear, which reduces the necessity for many additives, including those for antiwear and extreme pressure.

While, for most applications, biobased lubricants may be more expensive to purchase, the extra expense can often be

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2. Suszkiw, Jan, *Statue of Liberty Goes Green With Soy-Based Elevator Fluid*. Oct. 2004. Agricultural Research. Available at: <http://www.ars.usda.gov/is/pr/2004/041019.htm>.
3. Suszkiw, Jan, *Biodegradable Lube for Metalworking Operations*. May 2006. Agricultural Research. Available at: <http://www.ars.usda.gov/is/pr/2006/060508.htm>.

offset by the energy savings of higher lubricity. This is especially true in high-temperature applications.

High VI. The lower an oil's viscosity index (VI), the more change in viscosity occurs at both low and high temperatures. So lubricants with a high VI remain relatively stable over a wide range of temperatures.

Vegetable oils have higher VIs than comparable mineral-based oils (high VI mineral-based oils are available but are more expensive). While basic mineral-based oils have a VI of 90 to 120, the VI range for equivalent viscosity vegetable oils is 200 to 250.

Safer. The flash point of soybean oil is 326 C, while the flash point of mineral oil is 200 C. This reduces fire hazards in many applications including foundries, metalworking and even in building elevators. STLE-member Dr. Lou Honary, University of Northern Iowa professor and director of the UNI-NABL Center, found a way to make them even safer—and better. He and his colleagues developed a way to process biobased greases using microwaves.

“The efficiency of using microwave heating for the reaction process allows us to create vegetable oil-based greases that will be more oxidatively stable and cost less,” he explains. “Microwave energy uniformly heats the entire product and, due to their polar nature, vegetable oils absorb microwave energy very effectively. This was a huge, huge discovery for us.”

Renewable and farmer friendly. Increasing dependence on international oil sources, the declining rate of production from older domestic oil fields and the decreasing rate of newly discovered oil reserves is sparking interest in alternatives. In addition, specialty crops such as high oleic soybeans grown for biofuels and bio-lubricants are potentially more profitable for farmers.

DEALING WITH DISADVANTAGES

While there are some misconceptions about biobased lubricants (see sidebar *Biobased misconceptions*), there are signifi-



Biobased lubricants enter the consumer market. (Courtesy of Environmental Lubricants Manufacturing, Inc.)

Biobased misconceptions



Dr. Lou Honary, director of University of Northern Iowa Ag-Based Industrial Lubricants Research Center, clears up the following three misconceptions about bio-lubricants.

- 1. Lubricants biodegrade in the machinery.** Biodegradable doesn't mean the lubricants will biodegrade in the application. In order for anything to biodegrade, microorganisms that are capable of breaking the lubricant down need to be present. These microorganisms exist naturally in soil but not in machinery. Honary explains, “For example, we have oil from 12 years ago sitting in a pie pan, and it still has full liquidity with no sign of oxidation. We've monitored hydraulic oils in machines for thousands of hours and we've not seen any biodegradation.”
- 2. If you mix plant- and mineral-based products, they'll coagulate and plug up the machinery.** Research and real-world use shows that this is not the case. Even with hydraulic oil made of 50% plant-based and 50% mineral-based oils, there is no congealing.
- 3. Using genetically modified soybeans reduces the lubricant's biodegradability.** Tests show that vegetable oils, regardless of their fatty acid content, biodegrade at about the same rate. All chemically and genetically modified oils tested at UNI-NABL have shown the same levels of biodegradability.

There's disagreement as to just how recyclable biobased lubricants are.

cant challenges—namely poor oxidation stability and poor low temperature properties. Those two major performance issues are effectively preventing widespread use.

Oxidative instability. One of the most important properties of lubricating oils and hydraulic fluids is oxidation stability. Oils with low oxidative stability oxidize rapidly at elevated temperatures in the presence of water.

When oil oxidizes it undergoes a complex chemical reaction, producing acid and sludge that polymerizes to a plastic consistency. Sludge may settle in critical areas of the equipment and interfere with the lubrication and cooling functions of the fluid. The oxidized oil also corrodes equipment.

There are several fatty acids present in vegetable oil, but only oleic, linoleic and linolenic have the potential for positive or negative impact. The poor oxidation stability of soybean oil occurs because of the presence of double and triple bonds in these fatty acids evidenced by higher amounts of

linoleic (having two double bonds) and linolenic (having three double bonds) structures.

Genetic plant modification, chemical modification and chemical additives all can increase oxidation stability, increasing cost at the same time.

High pour point. Pour point is the lowest temperature at which a fluid will flow, while cloud point is the temperature at which dissolved solids are no longer completely soluble, precipitating as a second phase that gives the fluid a cloudy appearance. In the petroleum industry, cloud point refers to the temperature below which wax in diesel (or biowax in biodiesels) looks cloudy. The presence of solidified waxes thickens the oil and clogs fuel filters and injectors in engines. The wax also accumulates on cold surfaces (e.g., tubings or heat exchanger fouling) and forms an emulsion with water. The low-temperature fluidity of unmodified biobased lubricants is inferior to mineral-based and synthetic lubricants.

The pour point of mineral-based lubricants ranges from -18 C to -30 C: canola and rapeseed oil are around -9 C while unmodified soybean lubricant is about -2 C and modified vegetable-based lubricants have pour points as low as -40 C.

The soybean pour point problem can be solved with chemical additives or blending with other fluids such as synthetic oils with lower pour points. The key to success is retaining as much of the lubricant's biodegradability as possible while keeping the cost down.

Price. Many biobased products are priced to compete with mid- to high-performance mineral oil products. But higher-priced products still can be justified for use in many applications where biodegradability, lubricity, viscosity and fire safety are especially important (see sidebar: *Price comparison between bio- and mineral-based lubricants*).

"We can synthesize a vegetable oil-based lubricant that is price competitive with synthetic lubricants," Sharma says. "Our current research target is to make lubricants for various applications by modifying the vegetable oil structure so that we can improve some of its disadvantages and still compete with synthetic-based oils."

Difficult to recycle. There's disagreement as to just how recyclable biobased lubricants are. Some, like Sharma, say that once the oil is used it's hard to restore to its original state—and recycling is even more challenging if it's mixed

Price comparisons between bio- and mineral-based lubricants

The current price comparison between biobased and conventional lubricants is as follows:⁴

- Hydraulic tractor fluid: biobased 1.5-2 times more.
- Food-grade hydraulic fluid: biobased 1-1.5 times more.
- Industrial hydraulic fluid: biobased 1-2 times more.
- Chainsaw bar lubricants: biobased 1-1.5 times more.
- Multipurpose truck grease: prices are equal.
- Soy- and cotton oil-based greases: biobased 1-1.5 times more.
- Rail curve grease: biobased 0.9 less cost-1.2 times more.
- Metalworking fluids: biobased 1-1.5 times more.
- Gear lube: biobased 1.5-2 times more.
- Retail soy lubes: biobased 1-1.2 times more.

4. Honary, Lou, *Biobased Greases and Lubricants: From Research to Commercialization*. Biomass R&D Technical Advisory Committee, National Ag-Based Lubricants (NABL) Center, University of Northern Iowa., 2007. Available at: www.bdisolutions.com/SiteDocs/.../P4_BRDAC27-2007.pdf.

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The environmental advantage of biobased lubricants is the biodegradability of the exhaust and leakage and not their recyclability or ultimate disposal.

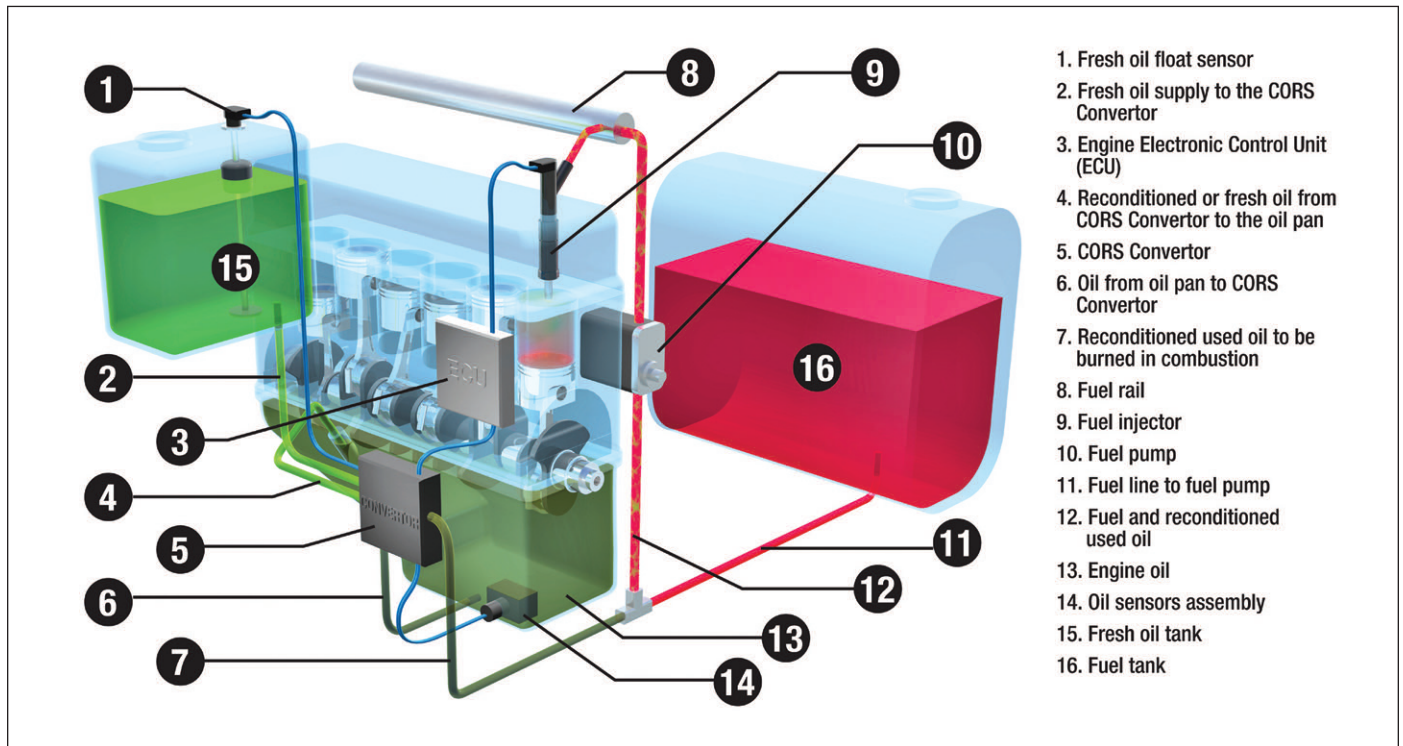


Illustration of the Continuous Oil Recycling System (CORS) as proposed by the UNI-NABL Center.

with mineral or synthetic fluids. Others disagree and see no reason why mixed fluids can't be processed and used again. Despite some efforts to recycle biobased lubricants, it's currently not profitable.

Because 50% or more of all lubricants are expelled into the air or ground during normal use, the environmental advantage of biobased lubricants is the biodegradability of the exhaust and leakage and not their recyclability or ultimate disposal.

MARKETS

The National Petrochemical Refiners Association reports that the annual production of lubricants in the U.S. is about 2.5 billion gallons. Hydraulic oils make up about 216 million gallons.

Biobased lubricant markets have the most potential where:

- The application is total loss.
- The application is indoors where low pour point isn't an issue.
- The application is in an environmentally-sensitive area where leakage and spill risk make biodegradability extremely important.

- The application is in equipment that processes or operates near food.
- The purchase is required (i.e., because of federal regulations).

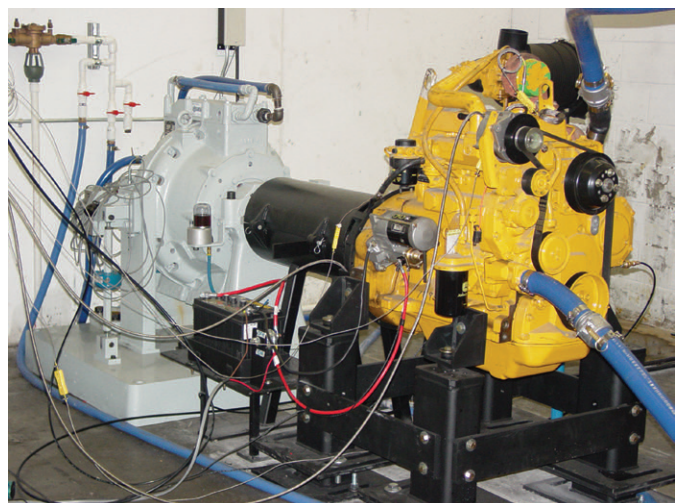
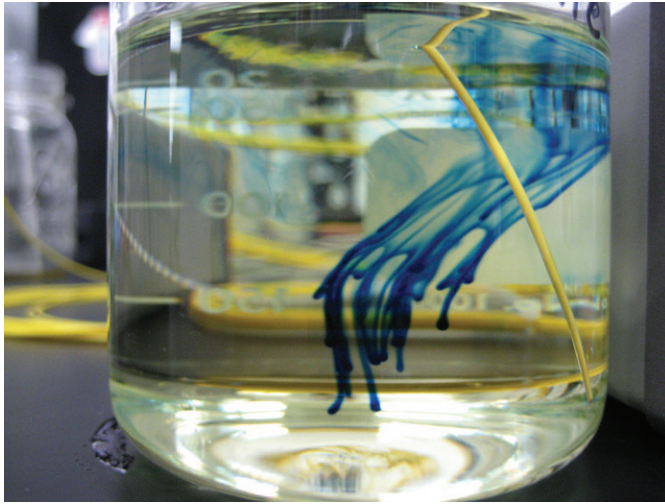


Photo of the Continuous Oil Recycling System (CORS) as proposed by the UNI-NABL Center.



Hot plate heating of vegetable oils showing uniform movement of fluids from bottom to the top due to convection.

Hydraulic fluids in environmentally-sensitive areas.

Hydraulic biobased lubricants are currently being used in equipment operating in areas such as parks, farms, waterways and golf courses. Most biobased lubricant manufacturers are aware of this market potential and currently have and/or are developing products that serve areas most vulnerable to spills and lost-in-use applications.

Transformer fluids. In the early 1990s, Honary and others developed a soybean-based transformer fluid in response to a disastrous oil spill at an Iowa electric plant surrounded by agricultural land. Since then, utilities have eagerly embraced the environmentally friendly lubricant, and the market in that area remains strong. The United Soybean Board reports that future sales in that area are promising.

As European bio-lubricant providers know too well, the political climate can interfere with successfully bringing biobased products to market.

MWFs. In cooperation with the USDA and Alcoa, Sharma and colleagues developed the biobased rolling mill oil mentioned earlier, which Alcoa is currently using in four global aluminum rolling mill operations. The company also has expanded biobased fluid use into mold release and metal-cutting operations. Other biobased metalworking lubricant application successes make this a promising market.

Elevator hydraulic fluids. There are about 800,000 elevators operating in the U.S. and Canada, and about 75% are



Samples of biobased engine oils taken from diesel engine tests at the UNI-NABL Center.

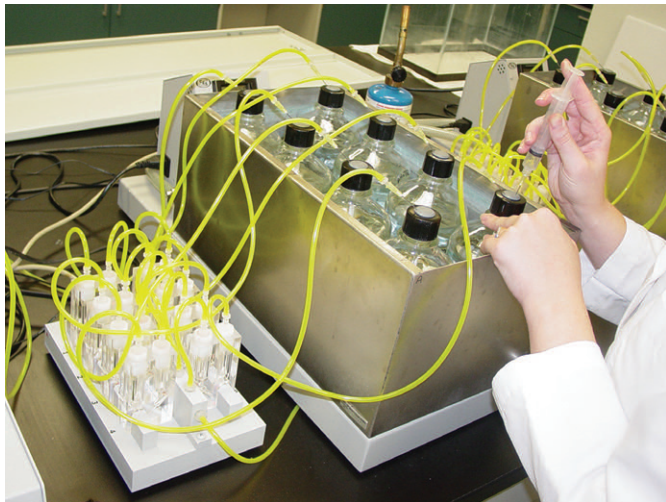
hydraulic vs. electric. Because most elevator fluids are used indoors, pour point is not an issue but price is. Currently the biobased version sells for about \$15 a gallon, while the mineral oil version is about \$9.50 a gallon. Despite this, some universities and hospitals have made the conversion, and the United Soybean Board believes this is a potentially strong market. Honary says the application provides for better fire safety, but due to the presence of moisture in the elevator reservoir environment, special formulations are needed to prevent sludge buildup and odor.

Food industries. Because 95% of vegetable-based hydraulic oil is actually edible, food manufacturing and service applications are perfect for biobased lubricants—especially since incidental contact with food is less of a problem. Since most of the processing is done indoors, there's little concern about cold temperature performance, which is one of the shortcomings of biobased oil.

Railroad lubricants. Many railroad lubricants such as gauge-face greases are lost-in-use, meaning they eventually leak or drain completely into the environment. So this is a salient application for a biodegradable product. According to Honary, biobased gauge-face greases are currently on the market and rail companies are buying.

Bar and chain oil. Bar and chain oil is another lost-in-use application involving external lubrication of the chainsaw's bar and chain. Given that nearly all chainsaws are used outdoors and most are used in environmentally-sensitive areas such as forests and farmland, this is a small but potentially profitable market. Bar and chain biobased lubricants are available, but the price is higher than their mineral-based counterparts.

Although crankcase oils are by far the largest segment of the lubricants market, stringent performance requirements, especially the need for oxidative stability, have kept biobased lubricants out of this market. But one company recently developed biodegradable G-Oil 5W-30 motor oil that received the American Petroleum Institute's seal of approval.



Preparation of samples and reference materials for 28-day biodegradability test, according to OECD 301F standard tests.

POLITICAL ISSUES

As European bio-lubricant providers know too well, the political climate can interfere with successfully bringing biobased products to market. The two issues that resurface regularly are food vs. fuel and genetic modification.

Because of the demand for biodiesel, there is not enough arable land in the U.S. to allow the biobased lubricant market to supplant the mineral- and synthetic-based lubricant market. In addition, some countries are dependent on soybeans for food.

One hectare of land will yield 446 liters of soybean oil every year, which will lubricate one piece of heavy equipment for about six months. Experts figure that in order to meet U.S. demand alone, soybeans would have to grow on 248 million hectares of land. Right now in total, there are only 190 million hectares of farmable land.⁵

Genetically modified crops have been blamed for everything from the dwindling monarch butterfly population to human allergies. Because biotechnology is both a political and scientific issue in Europe, some genetically modified products have been under review for more than six years—the review process in Canada, Japan and the U.S. is closer to six to nine months.⁶

THE FUTURE

At UNI-NABL, Honary and his team are working on several new processes and products.

In addition to the microwave-based grease processing technology, they are also improving the chemistry of vegetable oil-based greases.

“We are now narrowing down our grease-making process to making soap with one specific fatty acid,” Honary explains. “When a vegetable oil which is made of several fatty acids is reacted with, say, lithium hydroxide, the result-

ing grease includes several soaps mixed together, each with a different melting point. By reacting the lithium hydroxide with one specific fatty acid like oleic acid, the grease would be uniformly made as lithium oleate. This provides more predictability in the performance of the product at extreme temperatures and a more uniform overall performance.”

UNI-NABL is also trying to overcome problems associated with the presence of glycerin in the vegetable oil in its natural form. Glycerin in the oil could impact the performance of the product by absorbing water moisture and impact cold flowability or high-temperature emulsification.

UNI-NABL also is working on a new concept for the use of vegetable oils as diesel engine oil. The oil’s residency in the crankcase is reduced by burning small quantities of the engine oil along with the diesel fuel and replacing the oil in the crankcase with fresh vegetable oil. This concept is referred to as the Continuous Oil Recycling System.

Right now, there is no coordinated research program. Many lubricant companies are small and don’t have much research capability.

“Already we can make a very good lubricant basestock,” Perez says. “One of the key things we need to resolve is getting the vegetable oils into wider use. It’s a slow-growing market. There is a lot of collaboration going on, but there is also competition. The funding for research in these areas is not as high as it was at one time.”

Experts expect that, since the U.S. government is such a large purchaser of lubricants and fluids, once regulations and programs promoting the use of biodegradable products are fully in place and enforced, they will significantly increase biobased lubricant sales.

The biobased industrial products market will be driven by cost, performance, availability of resources and legislation. As the increasing demand on agricultural resources from the food and energy sectors continues to drive research in the area of alternative and economical feedstocks, prospects for biobased materials are good. **TLT**

CONNECT ON THE WEB

The USDA established a list of bio-preferred products, which is available at <http://www.catalog.biopreferred.gov>.

The United Soybean Board publishes a user guide and checklist of considerations for changing over to biobased lubricants. To download the user guide and checklist, log on to <http://www.soybiobased.org/lifecyclechecklist>.



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5. Ing, Adam, *Biobased Lubricants: A Viability Study*, 2009. Available at: www.journals.iss.org/index.php/proceedings53rd/article/view/1236/446.

6. *U.S. Mission to the European Union*, Foreign Agricultural Service, Aug. 27, 2009. Available at: www.useu.be/agri/usda.html.