OMNI TECH INTERNATIONAL, LTD.

BIO-BASED LUBRICANTS

A Market Opportunity Study Update

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BIO-BASED LUBRICANTS – A MARKET OPPORTUNITY STUDY UPDATE

STUDY OBJECTIVES

The aim of the current study is to update the report *Lubricants and Hydraulic Fluids – A Market Opportunity Study* dated January 1997. The areas to be addressed are recent technologies that affect the performance of soybean oil as a base lubricant, organizations that are active in the bio-lubricant area, new markets for soybean-based lubricants and the status of the markets identified in the original study with respect to size, growth and key factors that affect the markets. A comprehensive environmental and regulatory review is provided, including the evolving BioPreferred procurement program.

> *The 2013 amendments are made primarily to recognize the emerging availability of high oleic soybean varieties and to discuss several market changes and new technologies which have materially impacted the potential use of soybean oil over this five year period. This is not a comprehensive update and new data on market sizes is limited.*

CONCLUSIONS FROM ORIGINAL 1997 STUDY

The early study was unable to identify any substantial volume of soybean oil-based lubricants that were then sold commercially in the United States. One lubricant supplier was said to have sold soybean oil-based wire rope lubricants. There were a few hydraulic oils sold for use on golf courses and the like, based on rapeseed oil. The latter were largely imported from Europe where regulatory and environmental pressures required that biodegradable and renewable oils be used in areas where petroleum products were unacceptable. Some test work in the US looked promising in small volume potential areas, such as drip oils and wire rope lubricants.

The attitude in most market areas was that there was little if any incentive to switch from mineral oil-based lubricants to vegetable oil-based lubricants. There were no regulations and little environmental pressure forcing this change. In addition, vegetable oil-based products were generally less oxidatively stable, had some low temperature problems and were more expensive than mineral oil products.

The forecast at that time was that there would be regulations in the US that would require biodegradable oils to substitute for mineral oil based products in 3-5 years. Once these regulations were in place, the use of soybean oils and other renewable oils would find significant and growing markets in the US.

OVERVIEW OF THE RESULTS OF THIS UPDATE

On the positive side, there have been some new incentives for government agencies to seriously consider adoption of bio-preferred products as required by article IX of the 2002 Farm Bill and successive legislation. However, even in this area, the bio-preferred products must compete on performance and price. As was found to be the case at the time of the 1997 study, there are still no regulations to mandate adoption of vegetable oils in environmentally sensitive application areas to replace mineral oils as is increasingly the case in Europe.

The soybean oil replacement product that has achieved the most success is transformer dielectric fluid, also referred to as transformer oil. The acceptability has been high as the product shows both a performance and an economic advantage over mineral oil products in terms of a much increased fire point, increased service life of the transformer due to extended life of the insulating paper and the potential for much lower cost spill remediation due to favorable biodegradability and lower toxicity characteristics.

The largest single potential market for lubricants, crankcase oils, has not yet developed a product qualified to meet industry standards. Work still goes on in this area due to the potential cost advantage opportunity and products are close to being qualified although the soybean oil only represents a small percentage at present of the total formulated oil product. However, a small percentage in this market still represents a multi-million bushel soy potential if broadly adopted.

2013. The emergence of high oleic soybean oil as a commercial reality in the fall of 2013 has rekindled interest in soybean oil use in crankcase oils, though not as a triglyceride as produced in the soybean itself. Researchers have reported improved economics for the production of synthetic esters from the new high oleic oil. One of these, the production of estolides, discovered and patented by the USDA in the late 1990s is being aggressively pursued by a new company with backing from a producer of the new high oleic varieties.

The hydraulic fluid area has grown but the growth rate has been slow and still only represents a small percentage of the overall market for these fluids. The segment that has achieved significant success is elevator oils. A product developed by the USDA and licensed to and improved by Bunge/AgriTech has been successfully used by the Statue of Liberty, Penn State University and other municipal and educational institutions. Bio-based hydraulic fluids are finding increased use at military bases, national laboratories and national parks.

The use of soy in hydraulic fluids should benefit from the emergence of high oleic soybean oil. If HOSO is priced below other high oleic oils such as canola, it stands to gain share as a triglyceride in applications where high oleic canola is currently used. In applications where synthetic lubricants, such as polyalphaolefins are used, HOSO may match the performance of these more expensive lubricant basestocks. Total share will depend on the selling price of synthetics made from soybean oil.

The market for 2-cycle oils for marine engines, where the lubricant is used in combination with the fuel, was expected to be an application that would be regulated. The EPA has proposed and is about to issue regulations for the emissions from these engines. The traditional design of these 2-cycle engines cannot meet these new requirements. The response to this restriction has been to move to high pressure injection directly into the combustion cylinder, rather than carburetion. The emission restriction is thus met and the pressure to use biodegradable lubricants in this market segment has been diminished as much less unburned hydrocarbons are emitted.

Metalworking fluids have been a successful application for soybean oil lubricants. Alcoa and the USDA have developed a rolling oil lubricant that has met Alcoa's needs and is being used commercially today in plants around the world.

2013. The availability of high oleic soybean oil should allow increased use in metal working fluids replacing canola and high oleic canola in many applications where the better high temperature stability of a higher oleic/lower polyunsaturate oils is needed. If high oleic soybean oil is priced attractively, this could result in significant additional growth.

The total-loss lubricant area has reportedly not progressed very far. Bar and chain oils have not seen very much growth. Bio-lubricant products are available for this application but it is up to the consumer to make the choice. The bio-lubricants are more expensive and, without regulations, the choice is usually for the cheaper mineral oil based product.

Wire rope oils had the distinction of being one of the few areas where there was a regulation that promoted the use of biodegradable oils. It is unclear to what degree this is still the case today. In any case, the use of bio-lubricants in this application is small and does not seem to have grown.

The drip oil application also seems to have gone away. Work at the University of Nebraska based on a soybean-oil product was commercialized. However, buildup problems developed in the field, shutting down some wells, and it is understood that the product was withdrawn from the market.

LUBRICANTS AND FLUIDS - MARKET OVERVIEW

WORLD VIEW

From a global perspective, total lubricant demand is expected to be about 41.8 million metric tons, or about 13 billion gallons, according to a 2007 Freedonia report. Growth is expected to be about 2%/yr through 2010. The fastest growth will be in the Asia/Pacific region, with China being the major gainer.

In the world market, the segmentation by application area is:

- Engine oils – 48%
- Process oils – 15.3%
- Hydraulic oils – 10.2%
- All other - 26.5%

The geographical segmentation is:

- Asia/Pacific – 36.7
- North America – 28%
- Western Europe – 12.5%
- Rest of world – 22.8%

U.S. MARKETS

Sales of all lubricants in the US were in the range of 2.5 billion gallons in 2006, according to the latest National Petroleum Refiners Association report. This number is lower than the 3.6 billion gallons estimated by the above Freedonia study. The NPRA numbers are likely to be more accurate. The market is segmented according to the NPRA 2006 data as:

- Automotive – 56.1%
- Industrial – 21.2%
- Process oils – 18.1%
- Metal working – 2.1%
- Greases – 2.4%

The overall growth rate was about 1%/yr. Industrial oils were flat while automotive oils and metal working fluids were down, although some parts of these segments grew. The low growth has been attributed to the lengthening of oil change intervals and the higher performance oils being developed, in spite of the increase in vehicles and other machinery requiring lubricants.

EUROPEAN MARKETS

There is a great deal more market information available on lubricants in general and bio-lubes in particular in Europe than in the US. Perhaps this is due to the higher level of environmental awareness. Bio-lubricants have been in use in Europe for over 20 years. This is driven by regulations in some countries and perhaps a “greener” view of the environment and the need for renewable materials in other countries as compared to the US.

The total market for all lubricants in Western Europe is about 1.6 billion gallons, according to several published estimates.

According to a Frost and Sullivan study in 2007, European Bio-lubricants Market, the estimated usage in 2006 of bio-lubricants was 127,000 tons, or about 40 million gallons. Growth was estimated at 3.7%/yr between 2000 and 2006. Volume growth is still small although revenue growth is larger because of the higher price of the bio-lubes.

The overall use of bio-lubes in the European Union was estimated at 1% of the total lubricant use according to Rolf Luther of Fuchs Oil, Europe. This would be 16 million gallons if the overall lubricant use suggested above is 1.6 billion gallons. This number is lower than the Frost and Sullivan estimate.

INFRA, France estimates the total bio-lubricant market in Europe at 3.2% of the total lubricant usage, which is closer to the Frost and Sullivan estimate.

In the EU, some countries are more bio-oriented than others. It is estimated that bio-lubricants in Germany are about 15% of the total. The Scandinavians are not far behind at about 11%. Other countries, such as, France, Spain and the UK are below 1%.

The major vegetable oil in use in Europe for industrial products is rapeseed. However, not all the bio-lubricants are completely vegetable oil-based. In some countries, to get a label only requires that 50% of the oil is renewable. Thus, synthetic esters or even petroleum oils can be used in the formulation.

BIO-LUBRICANTS MARKETS IN THE UNITED STATES

MARKET DEFINITION

It is estimated that about 50% of all the oil used ends up in the environment. Petroleum –based lubricants, which are the leading type of base oil used in this industry, are poorly degradable and represent an environmental hazard when released. This represents a strong incentive to provide lubricants that are biodegradable. In addition, the rapid increase in the price of petroleum products in recent years, the increased dependence on offshore sources, the declining rate of production from older domestic oil fields and the decrease in the rate of finding new reserves has prompted governments and individuals to press for renewable products as replacements for petroleum products where practical. The bio-lubricant industry is growing based on these pressures, environmental concerns and sustainability.

Bio-lubricants may be defined generally as materials that are based on biodegradable and renewable base stocks. However, this definition is not universally accepted. In some areas, only biodegradability is considered in the definition. For present purposes, bio-lubricants will be defined as biodegradable and renewable materials.

Bio-lubricants do not have to be composed entirely of vegetable oil base stocks. They can be products derived from renewable oils, such as the fatty acids from fats and oils, reacted with synthetic alcohols or polyols to produce esters that can be considered bio-lubricants. Also, the natural vegetable oils can be treated to produce a modified product that is still biodegradable and renewable.

PRODUCT PERFORMANCE

Bio-lubricants based on vegetable oils have to overcome their inherent instability based on the presence of poly-unsaturated products in the natural oil to compete with products based on mineral oils. Great strides have been made since the original 1997 study. Soybean oil based products have been improved by chemical transformation, formulation and improved additive technology.

In addition, there have been several studies published showing the benefits of soybean oils in lubricant performance. See the article by Mathew T. Siniawski et al, from Loyola Marymount University in Los Angeles, CA, published in the *Journal of Synthetic Lubrication*, 2007; 24; 101-110.

In spite of the improvements in the performance of bio-lubricants, the market for these products has been slow to develop. The reasons for this are price and the lack of regulatory pressures to change. Bio-lubricant products are generally more expensive than their mineral oil counterparts, with some notable exceptions, so without regulatory pressures it is difficult to convince a user to change from what they know to be acceptable performance from traditional mineral oil based products.

CHANGE IS COMING – LEGISLATIVE INITIATIVES

The Food, Conservation and Energy Act of 2008, the Farm Security and Rural Investment Act of 2002, Presidential Executive Order #13423 and the Federal Acquisition Regulations (FAR) require government agencies to give preference to the purchase of bio-based products in place of petroleum-based products when reasonably competitive and suited to the application. It has taken the USDA several years to develop the product lists and definitions of what are now referred to as BioPreferred products.

The BioPreferred program was initially created by the Farm Security and Rural Investment Act of 2002 (FSRIA) to increase the procurement and use of biobased products by establishing:

1. A procurement preference program for Federal agencies and their contractors, and
2. A labeling program to enable the marketing of biobased products.

As determined by the Secretary of Agriculture, biobased products are commercial or industrial products (other than food or feed) derived wholly <u>or in significant part</u> of bio-based feedstocks including renewable agricultural materials (plant, animal, and marine materials) or forestry materials.

The USDA has established a list of BioPreferred products, which can be accessed from the link http://www.biopreferred.gov/Catalog.aspx Participation in this registration process is voluntary, and producers of bio-based products need not submit their products to qualify for preferred procurement. At this time there are 200 lubricant and fluid related products in the database. The product categories and number of products currently in each category are shown below:

Hydraulic oil – 127
Metal working fluids – 20
Penetrating oils – 20
Grease – 18
Concrete/asphalt release agents –11
2-cycle engine oils – 4
Firearm lubricants – 2

Although the various Federal agencies are required to consider BioPreferred products in their purchasing, they do have some discretion when the BioPreferred products are considered to be too high priced or performance is not equal to the mineral oil products. In addition, it has been recently decided that a re-refined lubricant product shall be given priority over a BioPreferred product.

At the present time (September 2008), the USDA does not have a mechanism to track or verify the purchases of BioPreferred products by the different agencies. They are working on getting better tracking but now only have general comments from each of the agencies on what BioPreferred product they have purchased or tested. For example, the USDA has used or tested 2-cycle engine oils, hydraulic tractor fluids and soy-based inks. Other agencies indicate that they used or tested lubricants or hydraulic fluids. This does not do anything to quantify the use of BioPreferred lubricants in government agencies.

The Federal Government is a very large purchaser of lubricants and fluids. Once the government agencies get this program more fully integrated, where purchases are transparent and data is easily obtained on the quantities and products purchased, this should be a major driver for sales of bio-lubricants.

ENVIRONMENTAL AND REGULATORY STATUS

OVERVIEW

Federal environmental regulations governing oil spill prevention, response planning, spill notification and cleanup make little distinction between petroleum oil and vegetable oil. By contrast, used oil waste management regulations exempt vegetable oil products. As a practical matter, however, many vegetable oil-based lubricants and fluids are not composed of 100% vegetable oil base stock, but rather are mixtures of petroleum and vegetable oils. In addition, finished vegetable oil-based products contain additives that may consist of regulated substances. Therefore, the actual federal environmental regulatory status of vegetable oil-based lubricants and fluids is more complicated than simply looking at whether the regulations distinguish between petroleum oil and vegetable oil. Examples are cited below:

- Storing or managing large quantities of vegetable oil only, mixed petroleum/vegetable oil, or petroleum oil only lubricant or fluid products subjects a facility to essentially the same federal regulations governing oil spill prevention and response planning.

- Federal oil spill reporting requirements (into waterways or adjacent shorelines) do not differentiate between spills of vegetable oil only, mixed petroleum/vegetable oil, or petroleum oil only lubricant or fluid products.

- Federal hazardous substances release reporting (to land or water) is based on the quantity of individual listed chemical substances contained in the spilled/released product. So any distinction in reporting would come not from what base oil stock is used but rather whether the spilled product contains any listed hazardous substance at levels high enough to require notification.

- Federal cleanup response regulations are site-specific taking into account the size and the nature of the spill. Responses can vary for spills of vegetable oil-based lubricant and fluid products compared to petroleum-based products based on ecotoxicity properties and rates of biodegradation.

- State regulations, rather than federal regulations, are most likely to cover the cleanup of the type of smaller releases, particularly to the land, associated with the use of lubricant and fluid products. Because state cleanup standards are usually risk-based, spills of vegetable oil-based products that are less toxic and more biodegradable are much less likely to require any significant cleanup action.

- Used lubricant and fluid products containing a mixture of vegetable oil and petroleum oil can be “recycled” under federal “used oil” management standards, which is a less costly approach than managing the used oil as a hazardous waste. Alternatively, a “used” vegetable oil only or a mixed petroleum/vegetable oil lubricant or fluid product that does not contain any contaminants that would classify it as a “hazardous waste” could be managed as a solid waste, an even more flexible and less costly management option.

In contrast to environmental regulations, federal procurement regulations do provide for a distinction between petroleum-based products and biobased products (including vegetable oil-based lubricants and fluids). Specific categories of biobased lubricant products, after being designated by the U.S. Department of Agriculture (USDA), are given purchasing preference by federal agencies. In addition, USDA is working to develop a “USDA Certified Biobased Product” label than can be used by manufacturers and vendors to identify and validate their products in the commercial and consumer marketplace as well as the federal marketplace.

Finally, potential federal and state activity regarding the reporting and regulation of greenhouse gas (GHG) emissions, as well existing voluntary programs such as the U.S. Environmental Protection Agency's Climate Leaders program, is increasing interest among industrial and commercial users in replacing or reducing the use of petroleum-based products. Vegetable oil-based lubricants and fluids can take advantage of this interest if life-cycle analysis can show reduced GHG impacts compared with petroleum based lubricants and fluids.

FEDERAL PREFERRED PURCHASING AND PRODUCT LABELING

Section 9002 of the Farm Security and Rural Investment Act of 2002 (FSRIA), as amended by the Energy Policy Act of 2005 and the Food, Conservation, and Energy Act of 2008:

- Requires Federal agencies to give a purchasing preference to biobased products designated by the U.S. Department of Agriculture (USDA), including products used in work performed under Federal agency contracts. (The preference applies unless an agency determines that the biobased products are not reasonably available within a reasonable period of time, fail to meet applicable performance standards, or are available only at an unreasonable price.)

- Requires USDA to establish a voluntary program and criteria for producers of biobased products to use a "USDA Certified Biobased Product" label.

PREFERRED PURCHASING

To implement Section 9002, USDA established the BioPreferred^{SM} program. Under the BioPreferred^{SM} program, USDA has to date designated 33 item categories for preferred procurement, which include the following nine lubricant, grease and fluid product categories:

- Hydraulic fluids for mobile equipment (44% minimum biobased content)
- Penetrating lubricants (68% minimum biobased content)
- Fluid-filled transformers
  - Synthetic ester-based (66 % minimum biobased content)
  - Vegetable oil-based (95% minimum biobased content)
- Metalworking fluids
  - Straight oils (66% minimum biobased content)
  - General purpose soluble, semi-synthetic, and synthetic oils (57% minimum biobased content)
  - High performance soluble, semi-synthetic, synthetic oils (40% minimum biobased content)
- 2-cycle engine oils (34% minimum biobased content)
- Hydraulic fluids for stationary equipment (44% minimum biobased content)
- Concrete and asphalt release fluids (87% minimum biobased content)
- Firearm lubricants (49% minimum biobased content)
- Greases
  - Food grade grease (42% minimum biobased content)
  - Multipurpose grease (72% minimum biobased content)

- Rail track grease (30% minimum biobased content)
- Truck grease (71% minimum biobased content)
- Greases not elsewhere specified (75% minimum biobased content)

Other item categories under consideration by USDA for designation include: chain and cable lubricants, corrosion preventatives, forming lubricants, gear lubricants, multi-purpose lubricants, water turbine bearing oils, slide way lubricants, engine oil, heat transfer fluids, and turbine drip oils.

In addition, the federal government has amended its Federal Acquisition Regulation (FAR) to add procurement preference provisions for biobased products. The FAR contains the uniform policies and procedures used by federal agencies when contracting to purchase products and services. The biobased provisions in the FAR include requirements that agencies consider the “maximum practicable use” of biobased products and services:

- When developing or revising their specifications, product descriptions and standards;
- In describing government requirements for products and services; and
- In developing contract source-selection factors.

Also, the Food, Conservation, and Energy Act of 2008 added a requirement that agencies report the following information annually to the Office of Federal Procurement Policy (OFPP): implementation actions and results of the agency’s review of its biobased procurement program, the number and value of contracts for the direct purchase of biobased products, the number of service and construction contracts that include biobased language, and the types and dollar value of biobased products used by contractors. In addition, the General Services Administration and the Defense Logistics Agency are required to submit each year to OFPP, to the maximum extent practicable, the types and dollar value of biobased products purchased by federal agencies.

The federal purchasing program for biobased products is beginning to take shape and reach a level of recognition among federal agencies that appears to be leading to increased purchasing of biobased products. As a result of federal action, a number of states are also beginning to implement their own purchasing preference programs. Similar to the role that the federal government has had in validating the purchase and use of recycled and recycled-content products, the federal biobased purchasing program can help validate and set an example for increased purchasing of biobased products in the industrial marketplace.

LABELING PROGRAM

USDA is currently drafting proposed criteria for the “USDA Certified Biobased Product” labeling program. USDA is working to determine what characteristics a product will need to get a label and what information will be displayed on the label. Among the issues under discussion are: biobased content levels, testing procedures, performance information or requirements, life cycle information, environmental and health benefits information, who can apply for the label, how long can the label be used, recertification processes, and compliance audit issues.

Once finalized, the program will allow manufacturers and vendors to use a USDA logo to identify their biobased products. The label will be available for finished products as well as intermediates used to make products. The intent of the program is to support product identification and use beyond the federal government and to educate and inform consumers. The USDA label, "USDA Certified Biobased Product," is expected to provide a strong third party validation for biobased products.

TECHNOLOGY ADVANCES

The oxidative instability of soybean oil as well as rapeseed oil and other vegetable oils is due to the presence of polyunsaturated fatty acids, as in linoleic acid and linolenic acid. Efforts have been made to modify the soybean oil to moderate the effects of these materials to provide a more stable material and a product more competitive in performance to mineral oil-based lubricants. The different approaches to this end include:

ADDITIVE TECHNOLOGY

Oil formulations, whether they are bio-based or mineral oil, are generally regarded as proprietary information. It is difficult to know the identity of the additives added to the soybean oil in those products that have been developed. Patents do not always give the answers. There are some indications from the patent literature that some investigators have developed stable products based on additive technology. An interesting study by Tribsys on the interaction of soybean oils with EP additives has been published.

OIL TREATMENT – CHEMICAL TRANSFORMATIONS AND POLYMERIZATION

There are many different ways to modify the multifunctional vegetable oils. Some reported changes that address the polyunsaturated problem include alkylation, acylation, hydroformylation, hydrogenation, oligomerization (polymerization) and epoxidation. *An article has been published by* Manfred Schneider entitled *Review – Plant-oil-based Lubricants and Hydraulic Fluids*– available at : http://www3.interscience.wiley.com/journal/112736853/abstract) *.*

No commercially available products based on these modifications have been identified, except perhaps on polymerization. There is some indication that polymerization is used to produce a stable hydraulic oil for elevator applications. Although it is possible that the end product oils are acceptably stable in the intended applications for some of these reported transformations, the added processing cost is likely to be a hurdle limiting broad commercial adoption, except perhaps in the case of polymerization.

Dow Chemical has developed a soy monomer that is currently being processed into a soy polyol for plastics and this monomer may be suitable, according to Dow, for chemical transformation into the lubricants market.

Additional work in this regard was the subject of a PhD thesis published in 2005 by Phuong T. Tran of Michigan State University entitled *Engineered Soy Oils for New Value Added Applications.*

2013. Multiple research projects have been conducted to develop a synthetic ester based on vegetable oils. Notable among these is a process developed by USDA and first patented in the late 1990s to produce a type of ester called an "estolide." The process and product were disclosed to USB as early as 2002 by the first licensee, Lambent Technologies. The process requires a high level of mono-unsaturated fatty acids such as oleic acid. The end product showed good potential for overcoming the oxidative stability and low temperature problems associated with soy and other vegetable oils in the triglyceride form. However,at the time, the process was deemed to be too expensive to be commercially viable and other issues, including the use of a sulfuric acid catalyst, made the product unattractive as a candidate for crankcase oil use.

In 2013, the process has been licensed to a new company, Biosynthetic Technologies, which claims that with the availability of high oleic soybean oil and the use of an improved, higher yielding process based on a new catalyst, the estolide product should be commercially viable. USB has entered into a research contract with Biosynthetic Technologies to fund engine stand testing for gasoline engine crankcase oils based on this improved estolide. Objective third party sources are optimistic that the new synthetic material based on high oleic soybean oil will allow the formulation of crankcase oil which will pass API GF-5 testing.

TRANSESTERIFICATION

This chemical transformation fits in with the above category but is isolated here because it is likely used in some bio-lubricant products. It is well know that improved lubricant performance can be achieved by replacing the glycerol part of the vegetable oil with other polyols, such a trimethylolpropane, neopentyl glycol or pentaerythritol. These materials are considered to be semi-synthetics and are biodegradable but not entirely renewable.

GENETIC MODIFICATION

Research on genetic modification of soybean oil and other vegetable oils has been an ongoing effort for many years. Major life science companies (Monsanto and its seed company holdings such as Asgrow and DuPont and its seed company Pioneer) have been active in the area, along with numerous university and USDA researchers, with considerable support from the United Soybean Board. Much of this research has focused on reducing both saturated and polyunsaturated fatty acids and some varieties are already being marketed with improved cold flow properties and somewhat increased oxidative stability.

DuPont and Monsanto at the USB Technical Advisory Panel (TAP) meeting in 2007 reported that they continue to make progress on the introduction of mid to high oleic content soybean oils. DuPont has a transgenic high oleic (>80%) with less than 3% linolenic that is at stage gate six (out of eight stage gates) that is being commercially evaluated. Monsanto is already marketing a low linolenic (less than 3%) low saturate (about 9%) soy oil as **Vistive™I** that has been developed by conventional breeding and is at stage gate three (out of four gates). Monsanto also reported they were developing **VISTIVE III** that is obtained by breeding **VISTIVE I** with a transgenic variety to achieve a high oleic IP basestock that could be more useful in lubricant applications. The reported target for the fatty acid profile in **VISTIVE III** is 73% oleic and less than 3% each of saturates and linolenic acid.

These advancements are significant for industrial lubricants and samples are being evaluated by Valvoline and others for use as high temperature engine oils and hydraulic fluids.

Monsanto and DuPont are also investigating the potential for elevating the total oil content above the current average of 11.7 pounds per bushel of beans.

One of the more promising developments for lubricants comes from DuPont/Pioneer. They have announced plans for the commercialization and sales of high oleic soybean oil (HOSO) in 2009. The soy varieties will be sold under the brand name TReUS®. The oil is desirable for food applications since it will not require hydrogenation to allow prolonged storage and thereby will allow food manufacturers to avoid both the transfat and saturated fat issues in food labeling. This product should be a valuable addition to the soybean oil family. It has greatly reduced the chemical entities that generate the stability problems, linoleic and linolenic acids. These reductions are made up by the substantial increase in the oleic acid component. The following is a summary of the percentage composition expected in the new DuPont high oleic soybean oil (HOSO) product compared to unmodified soybean oil.

	Stearic / Palmitic 16:0 &18:0	Oleic 18:1	Linoleic 18:2	Linolenic 18:3
Conventional soybean oil	15	22	55	8
High oleic soybean oil	4-5	78-82	2-6	<3

The HOSO numbers above represent the composition range for the 16 test plots around the US in 2007. It is obvious that this new soybean oil will have a substantial increase in stability and performance over the unmodified material. It will carry the genetically modified (GM) label and the cost will likely be higher as these GM materials require special handling and isolation from the unmodified oils.

DuPont has advised that the crop in 2009 will be relatively small and that it is all committed. The future availability of this product should provide a boost for the bio-lubricant industry. Certainly, formulations will have to be modified to take advantage of the new soybean oil composition. In fact, this may provide an opening for those companies that have not been able to produce lubricants that meet the specifications required. This could be particularly true in the crankcase area where stability is a major problem. DuPont and Valvoline are understood to have discussed the availability and development of crankcase oils from HOSO.

2013. Long awaited, the first crop of high oleic soybean varieties will be harvested in the fall of 2013. There will initially be two different lines, one from Monsanto trade named Vistive Gold, and the other from DuPont/Pioneer, trade named Plenish. Both lines are expected to contain approximately 75% oleic acid in the oil. There will be some differences in content of saturated and polyunsatured fatty acids, but current speculation is that soy crushers who will handle the processing and oil extraction will not attempt to segregate the oil from the two high oleic lines.

This level of oleic acid should be sufficient to allow expanded lubricant use in some applications, such as metal working fluids and potentially hydraulic fluids, 2-cycle engine oils and others. Currently other high oleic oils such as high oleic canola are preferred in some metal working applications, so the use of high oleic soy will depend on the competitive price of soy versus these other oils. In products like hydraulic fluids, where conventional soy may already be used, HOSO should allow a reduction in the need for additives such as anti-oxidants and pour point depressants. Assuming that HOSO will sell for some premium over conventional soybean oil, the reduction in additive cost will have to be sufficient to offset the premium for the basestock.

As mentioned above, high oleic oil has some advantages in making various synthetic esters and other compounds used in lubricants. This includes the estolides, discussed previously but also may include such products as azelaic acid which is currently made via ozonolysis of the oleic acid in beef tallow. If the higher yield and lower processing cost of HOSO as a feedstock for ozonolysis is sufficient to overcome the cost premium over tallow, use in lithium greases and specialized metal working fluids made from azelaic and/or pelargonic acids may become a new lubricant market for soy.

NEW APPROACHES

A potentially novel approach to improving the stability will be forthcoming from a new company, Elevance Renewable Science. This company is a joint venture between Cargill and Materia, a Pasadena, California based company. Materia is a company that specializes in metathesis chemistry. *Metathesis* is a bimolecular process involving the exchange of bonds between the two reacting chemical species, which results in the creation of products with similar or identical bonding affiliations. To illustrate, consider two chemical species, AB and CD, which react to give AD and CB:

$$AB + CD \rightarrow AD + CB$$

There are many ABs and CDs in vegetable oils and this type of chemistry could react out the undesirable parts of the oil. This is an interpretation of their intent. The company was not prepared to discuss any of their future plans or current activities. It is believed that this chemistry could hold great promise for future modified soybean oils. One unresolved question is of the biodegradability of the new potential products and whether they would they be considered renewable or synthetic.

2013. The fact that high oleic soybean oil is predominantly one fatty acid type (oleic) simplifies the processing and separation of various chemicals made through the olefin metathesis reaction as well as many other types of chemical processing. Discussions with Elevance, which is no longer a joint venture, indicate that HOSO will find favor in many proposed applications under development by the company, including lubricants. As with all markets, the purchase cost and availability of HOSO will determine its use as a feedstock.

All of the above approaches are aimed at improving the stability and performance of soybean oil and come at some additional cost beyond the feedstock oil itself. This is part of the reason for the higher price for the successful soybean oil products when compared to the mineral oil competition. Although mineral oils have seen dramatic price variations in recent years, so have vegetable oils. In some cases, the differences between the two product bases have narrowed considerably.

MARKETS FOR BIO-LUBRICANTS

CRANKCASE OILS

Crankcase oils are by far the largest segment of the global lubricants market, representing a demand in excess of one billion gallons per year in the US alone. It is also a segment which is extremely demanding in performance requirements, particularly in long-term oxidative stability where vegetable oils face inherent barriers not yet successfully surmounted. While the cost and technical sophistication required for research and qualification to industry standards is forbidding, the longer term opportunity has drawn the attention of the major industry leaders.

Economic Factors

Valvoline is a company that wants to put engine oils on the market that competition does not have. A perfect example is engine oil for high mileage cars. Valvoline was first to market such an oil and started what became a new and profitable market segment. They saw the use of a renewable component as a way to come up with yet another unique product. Product development was helped by the United Soybean Board’s partial financial support of Valvoline’s own research efforts.

Technical Factors
The extremely high viscosity index and very low volatility of soybean oil (and other bio- fluids) attracted Valvoline interest because of the potential to allow savings in viscosity treatment to obtain a given viscosity grade. In contrast, the need for additives to stabilize soybean oil at high and low temperatures was recognized.

Balancing Economic and Technical Factors
The cost of finished engine oil containing a bio-fluid and extra additives needed to be balanced with market profit opportunities. With changing soybean costs relative to petroleum base oil costs during early stages of the development program and currently with the rapid changes in costs of all raw materials, economic considerations on any given day were recognized as uncertain at best. Instead, Valvoline took a strategic look at this objective. This approach, and continued USB support, maintained their reasonably high level of interest, which continues today.

Industry Standards
Reputable marketers of high quality engine oil take all steps necessary to meet performance standards set cooperatively by industry participants (oil marketers, additive suppliers, engine builders, etc.). Thus Valvoline has conducted extensive engine and bench testing in their quest for a formulation that fully meets the latest industry standards. For the US market targeted by Valvoline for oil with a bio-based component, any or all of the following industry standards need to be met: American Petroleum Institute (API) SM, API Energy Conserving and International Lubricant Standardization and Approval Committee ILSAC GF-4. The Sequence IIIG (oxidation stability), Sequence IVA (valve train wear), Sequence VG (low temperature sludge and varnish), and Sequence VIII (bearing corrosion) are engine tests required for API SM. In addition, the Ball Rust Bench Test is needed for these specifications. The Sequence VIB (fuel economy) is also required for (ILSAC) GF-4 and for an API claim of Energy Conserving. Passing performance must be demonstrated in all of these tests to support API licensing against the three industry standards listed above.

For mineral oils and poly alpha olefins, API guidelines allow engine test results on some oils to be used as appropriate in the evaluation of others. However, API recently reaffirmed that all required Sequence Engine Tests must be run and passed with oil containing any bio-fluid content.

Valvoline Formulation and Testing Experience
Of the varieties of soy available for product development, those with oleic content at the level found in conventional soybean oil were not considered because of known deficiencies in high temperature stability. Initial Valvoline studies were conducted with mid-oleic (53% oleic minimum) soybean oil. Even with this variety, stability at high temperature and maintaining good flow properties at low temperature were main hurdles that needed to be solved.

Valvoline solved the low temperature flow properties issues by using selected cold flow improver / pour point depressant additives. The exact additive combination used by Valvoline is considered proprietary.

Once cold flow issues were resolved, Valvoline tackled bearing corrosion as measured by the Sequence VIII engine test. Considerable work led to selection of a variety of corrosion and oxidation inhibitors that fully protect copper-lead bearings in engine service. Again, the exact additive combination used by Valvoline is considered proprietary. Further testing indicated that other than the Sequence IIIG and Sequence VIB, engine test issues were relatively easy to resolve.

The Sequence IIIG remains the most critical hurdle. Passing this test also has critical bearing on passing the Sequence VIB fuel economy requirement. If oil oxidizes it thickens, reducing the oil's ability to provide improved fuel economy.

A reduction in soybean oil content from 20% to 5%, and further modification of antioxidants, improved Sequence IIIG performance, but a test pass was not yet obtained. At this point, Valvoline efforts shifted to engine oil with 5% high oleic soybean oil. Performance extremely close to a passing Sequence IIIG has been obtained. A new bench test, the ROBO, has been used to predict Sequence IIIG performance and to select the best candidate for testing. Other engine test strategies carry forward from mid-oleic testing to the high oleic soybean oil. Time will tell, but Valvoline is optimistic. Once passing engine tests are obtained, Valvoline will initiate field testing.

Key Lessons of the Valvoline Program

Several key points are evident from experience gained during the Valvoline project:

- If formulators simply replace mineral oil base stock in a lubricant with a soybean or other bio-fluid component, even at low levels, performance of the lubricant will likely be degraded.

- Additive selection can regain performance lost by addition of a bio-fluid.

- The lubricant containing a bio-fluid component must be fully tested to prevent poor performance in customer equipment.

- A reputable oil marketer is needed to conduct the necessary testing in the laboratory and in field tests to ensure performance in customer equipment.

2013. The intent of the statements above was to point out that experience indicated that no level of formulation with various additives had been successful in making crankcase lubricants from soy or other unmodified triglycerides, which would compete in performance and economics with the then current petroleum and synthetic basestocks.

The use of the term "bio-fluid component" was an overstatement. Certainly, technology today does allow the production of synthetic materials made from high oleic soybean oil and potentially other biobased materials. Further the economics of making a lubricant have changed significantly since 2008. Even as the last version of this report was being written in early 2008, the price of crude petroleum was rising quite significantly and with it the price of all competing lubricant basestocks also rose.

Today it is possible that a synthetic material based on high oleic soybean oil, such as the estolides discussed earlier, will prove to be equal to or even superior in many functional respects to current lubricant basestocks and even workhorse synthetics such as polyalphaolefins (PAO.)

TRANSFORMER FLUIDS

Transformer dielectric fluid, also referred to as transformer oil, has undergone various significant changes over recent decades. At one time, polychlorinated biphenyls (PCBs) were used extensively. The fire retardant nature of this chemical was thought to be a highly desirable property. The disadvantage was its toxic nature and the lack of biodegradability. Any spills of the product dictated an extensive and expensive clean-up process to remove all traces of the material from the soil. In the 1970s, PCBs were banned due to their health and environmental hazards. New transformer oils were developed. They included naphthenic mineral oil which was the major product in early 2000 when the total U.S. consumption was about 45 million gallons per year according to a Cargill report. More specialty type products were also developed and marketed including high molecular weight hydrocarbons, synthetic esters and silicone fluid manufactured by Dow Corning.

A soybean-based transformer fluid was devised in the early 1990s after a costly oil spill occurred at Waverly Light and Power, an electric utility in Waverly, Iowa. Realizing that his utility was surrounded by rich Iowa farmland, Glenn Cannon, Waverly's general manager, knew there had to be an environmentally safe solution to petroleum-based transformer oils. He partnered with Dr. Lou Honary, Director of the University of Northern Iowa's Ag- Based Industrial Lubricants Research Program (ABIL), ERMCO and Cargill to develop the soybean-based transformer fluid known as BioTrans 1000. The fluid was proven to enhance transformer performance, was environmentally friendly and could be used in a variety of electrical applications.

During 2003 the development of soybean oil as a transformer fluid was accelerated, under a Cargill program. This work was in part financed by the United Soybean Board to evaluate several properties and performance characteristics. The result was reported in detail at the September 22, 2004 United Soybean Board Technical Advisory Panel on Lubricants and also in a Cargill report “Development of Soybean Oil-Based Transformer Fluid” dated February 20, 2004.

In September of 2004, it was announced that Cargill Industrial Oils and Lubricants and Cooper Power Systems would work together on the commercial development of Cooper’s soybean-based transformer oil EnviroTemp® FR-3™. Cargill ceased production of its competitive dielectric fluid, BioTrans, in order to devote major effort towards the Cooper product. Six months later, an international expansion of the alliance covering the soybean- based transformer oil was announced. Cargill began manufacturing Cooper’s EnviroTemp® FR-3™ at facilities around the world in order to meet growing demand.

The US market is also served by a vegetable-oil-based product offered by ABB under the Biotemp® brand.

The present generation of vegetable-oil-based transformer fluids may be characterized as premium products offering performance which in some respects is far superior to the conventional mineral-oil-based products they replace. In addition to biodegradability and low toxicity with corresponding spill remediation savings potential, they offer the safety advantages of a fire point above 300°C versus 145°C for the mineral oil product. The service life of a transformer is substantially increased due to the typically five times greater life of the insulating papers inserted between the windings. In contrast, the present generation of bio-based fluids are not as tolerant of extremely low temperatures as are the mineral oil products, typically limiting installations at present to exclude areas subject to extreme winter conditions. In addition, the excellent performance experienced in the US market is linked to the standard use here of sealed transformer systems; in Europe, the standard vented systems in use place a higher demand on oxidative stability of the fluid used.

Some examples of conversion to the relatively new soy-based transformer fluid were recently published:

Commonwealth Edison (Com Ed) is replacing 4000 transformers now using petroleum- based transformer fluid with new soy oil fluid and will continue to buy 4000 new soy oil insulated transformers each year and will buy additional soy containing ones for any oil transformers that must be replaced. Com Ed currently has more than 500,000 transformers in service.

Xcel Energy, which serves eight Midwestern states from headquarters in Minneapolis, announced that it would switch to EnviroTemp® FR-3™ soy-based transformer oil produced by Cargill and sold by Cooper Power Systems. The company plans to use soybean oil in over 13,000 transformers. It joins several other large electric companies in making the change to soy transformer oil, such as Alliant Energy which announced its conversion to soy earlier. Based on their annual purchasing history of distribution transformers, Xcel Energy would avoid the use of approximately 336,000 gallons of mineral oil by specifying FR-3™ fluids.

It is apparent that the sales of soy-based transformer oils are off to a very good start. Future sales look promising.

It is estimated by Cooper Power Systems that the current (2008) sales of soy-based transformer oil will be about six million gallons/year, increasing to 20 million gallons by 2011.

The total size of the U.S. transformer oil market is estimated at about 60 million gallons per year. The Cargill product will be produced in the US, Brazil and elsewhere in order to serve the growing world market potential.

ELEVATOR HYDRAULIC FLUID

The Agricultural Research Service (ARS) and AgriTech, now Bunge/AgriTech, developed a soybean oil-based hydraulic fluid that met the requirements for the Statue of Liberty's elevators, a high-visibility demonstration project. The fluid was approved for use in the Statue of Liberty and the technology was licensed from the ARS. The Bunge/AgriTech Brands group sells this product broadly, although the commercial market has been slow to adopt this change. The product has the advantage of not requiring heating in the winter and cooling in the summer at the Statue of Liberty location, because of its high viscosity index. Their primary customers are universities (Penn State is a large consumer) and hospitals. Otis, the largest elevator company, has reportedly not as yet been a buyer.

The price for these oils is about $15.00/gallon in drums compared to $9.50/gal for the corresponding mineral oil product. This price difference provides a competitive hurdle today except where considerable weight is placed on environmental considerations.

Another supplier of elevator oils is Hydro Safe Oil Division. They sell a range of viscosities for elevators. They have commercial customers as well as some government agencies. They expect to sell about 40,000 gallons this year. The Hydro Safe hydraulic oil is made from canola oil and is priced at $14.82/gallon in drums. They have been getting many inquiries for their product and they expect their business to grow. It has been reported that the Army has tested their fluid for use in tanks and are expected to order significant quantities.

The market for elevator oils is substantial. There are about 800,000 elevators operated in the US and Canada according to the National Elevator Industries trade group, of which approximately 75% are hydraulic. A conservative estimate is that that the average elevator will require 400 gallons to fill the unit, so on a fill basis the utilization is about 240 million gallons. The annual makeup rate is reportedly about 8%/yr, so the makeup volume can be estimated at about 20 million gallons per yr.

This is a substantial market potential and should attract the attention of the bio-lubricant business. The realistic hurdle in this market, like many others, is that there are no regulations to mandate adoption when the price is substantially higher for the bio-based materials. The Bunge and Hydrosafe products provide a benefit in stable viscosity over a range of temperatures, fire resistance, sustainability and biodegradability. The cost of a spill remediation using a mineral oil product could be an offset to the higher price of the base oil, although at present this benefit is subject to varying regional regulatory guidelines.

The above is an example of a new commercially successful adoption of a soybean oil-based industrial product introduced since the original 1997 study.

OTHER HYDRAULIC FLUIDS

After crankcase oil, the hydraulic fluid area represents the largest volume potential. There are about 225 million gallons/yr of hydraulic oils sold in the US today. Growth is relatively flat so there is not much change in overall demand.

Because this area has so much potential, most bio-lubricant suppliers have a range of products to meet the needs of this industry. Most contacts have indicated that this is a small but growing application area for bio-lubricants. The best estimate of the market share for bio-lubes in this sector today is about 1%. This number was not disputed by several contacts that are in or associated with this business.

If 1% is correct, this represents about 2 million gallons/year. Hydraulic oil bio-lubricants are used in some strategic areas such as national parks, military bases, national laboratories, golf course equipment, food services, some farm tractors and hydraulic elevators. It is the latter that is among the largest users of hydraulic fluids (see above).

2013. High oleic soybean oil will likely replace conventional soybean oil in some hydraulic fluid applications. The improved low temperature properties and oxidative stability of HOSO should allow a reduction of additives resulting in lower cost formulations when compared to conventional soybean oil.

Some lubricant manufacturers report sales of hydraulic fluids made from high oleic canola. They report that when HOSO is readily available and if it is lower in cost than high oleic canola, they would switch to HOSO.

They market for synthetic basestocks in hydraulic fluids is relatively small. If a synthetic lubricant made from HOSO does become available at a competitive price to other synthetics, that new product could win some share, especially in environmentally sensitive applications.

METALWORKING FLUIDS

Another successful application of a soybean oil lubricant came about in the rolling oil area of metal working. Alcoa had a CRADA (Cooperative Research and Development Agreement) with the USDA to develop a bio-based rolling mill oil. The development was successful and Alcoa is using this oil in four aluminum rolling mill operations around the world. They have also expanded the use of bio-based fluids in metal cutting and casting (mold release). Alcoa makes some of their own bio-fluids and buys some. They report that the bio-based oil provides a cost savings compared with the traditional product. Part of this may be due to the carbon credits available in Europe.

Current usage for Alcoa is reportedly about 100,000 gallons/year, mainly in rolling mill oils. Significant growth is expected over the next 3-5 years.

Vegetable oil-based cooling and cutting oils have also found success. A June, 2008 article in Lubes 'n' Greases by Ralph Garcia of Houghton reports on the success of an unidentified vegetable oil in place of a mineral oil-based product at an Eaton plant. The bio-lubricant showed substantial savings in coolant waste stream treatment and disposal, biocide use, tool savings and increased grinding throughput. No numbers or product descriptions were provided. Houghton does not presently have a metal working fluid on the USDA BioPreferred list.

An interesting PhD thesis was published in 2006 by Shelie Miller entitled *Comparative Life Cycle Assessment of Soybean Based and Mineral Oil Lubricants in Aluminum Rolling*. A paper based on this research was presented at the Society of Tribologists and Lubrication Engineers (STLE) conference on May 15, 2005.

2013. High oleic soybean oil will likely replace conventional soybean oil in many metal working applications. The improved low oxidative stability of HOSO, should allow a reduction of additives resulting in lower cost formulations when compared to conventional soybean oil. High oleic canola oil currently enjoys this position in the market. Assuming HOSO is less expensive and performs essentially the same, HOSO could replace HO canola.

2-CYCLE ENGINE OIL

At the time of the 1997 market study, it was considered that mineral oil-based 2-cycle lubricants were a prime example of a product that needed to be replaced, especially in marine applications. These 2-cycle engines employ a pre-mix of fuel and lubricant which is regulated through carburetion. The engines were high emitters of unburned hydrocarbons, particularly from the oil. This resulted in large amounts of unburned hydrocarbons entering the waterways and the atmosphere.

In response to this, the EPA has proposed and is about to issue new regulations on the emissions from 2-cycle engines. According to the National Marine Manufacturers

Association (NMMA), this will be the end of the 2-cycle engines as they are known today; they cannot meet the strict emission standards being proposed.

In response to this, the marine engine industry has developed a new high pressure fuel injected engine that is more efficient, requires less lubricant and can meet the EPA emission standards being proposed. These E-TEC engines will replace all new 2-cycle engines of present design in 2010.

Because of the clean and efficient engines that are to be introduced, the pressure to find lubricant substitutes is diminished. There will be only small amounts of unburned hydrocarbon from the oil, thus reducing the incentive for requiring bio-based lubricants.

BAR AND CHAIN OIL

The bar and chain oil market is small, estimated at 2-3 million gallons per year. It is a total oil loss application as the lubricant serves to externally lubricate the bar and chain of the saw. All the expelled oil enters the environment, so it is another area where it makes sense to replace the mineral oil products with bio-lubricants. This is done in Europe but the present US demand for bio-lubes in this application is very limited. The major chain saw marketers indicate that the choice is up to the consumer as they fill the chambers after the saw is purchased. There are bio-lubes available, but the price is higher than the mineral oil counterparts. The choice made so far is usually for the lower cost product. It is estimated that only about 5% of the bar and chain oil purchased is a biodegradable product. This amounts to about 100,000 gallons per year in the US.

A positive indication in this area is that the major chain saw company Stihl has reportedly been receiving an increasing number of inquiries about bio-based lubricants for their products. This may well be due to the Federal requirement to consider bio-based products for all lubricant applications.

WIRE ROPE GREASE

At the time of the earlier study, lubricants for wire rope applications were considered to be an area that had some regulations in effect. It was reported that Coast Guard regulations prohibited ships from conducting operations that produced a visible sheen in the waterways. This sheen developed because the wire rope, used for anchors, dredges and related applications, had grease lubricants on and in them. There were penalties imposed if these sheens were generated, except if biodegradable lubricants were employed. This market was then estimated to be small, about 500,000 gallons per year, for lubricants added during manufacture and perhaps an equal amount used as dressing in use. The total is therefore small, likely a million gallons per year in the US.

One lubricant supplier reported that their customers complained to the Coast Guard that the cost of the bio-lubricants was too high for them to continue their use. Apparently, the regulations were then eased.

However, another lubricant supplier indicated that the regulation has not eased. It was indicated that very little bio-based lubricant is used at present in this sector. It is up to the customer for the wire rope to specify that they want bio-lubricants in their rope, but this does not happen often as yet.

RAILROAD LUBRICANTS

There are two types of rail-related lubricants that are total loss-type products, top-of-rail lubricants and gauge face greases. The top-of-rail lubricants are used to control friction; they are not there for wear control. Neither petroleum nor bio-based materials reportedly meet their needs. The product that they use is a water-based inorganic material that dries and controls friction. The market for this area is small, about 600,000 gallons per year.

The gauge face grease application can use bio-based products. Norfolk Southern has evaluated a soybean oil product but reportedly did not adopt it. Dr. Honary indicated that ELM does currently sell this product to the railroads. The market potential for these greases is claimed to be about 10 million gallons per year.

SUPPLIER COMPANIES AND PRODUCT LINES

The BioPreferred program operated by the USDA lists all bio-based lubricants that companies choose to register. There are some 200 products currently listed in the categories as follows:

Hydraulic oils – 127
Metal working – 20
Penetrating oils - 20
Greases - 18
Concrete and asphalt release agents – 11
2-cycle engine oils – 4
Firearm lubricants – 2

There are a large number of companies associated with these categories. The BioPreferred list for each category established by the USDA with a list of products, the companies offering them and a comparison of their features can be accessed from the link http://www.biopreferred.gov/Catalog.aspx

It is interesting to note that of the 20 largest lubricant suppliers around the world, only two companies have an oil on the BioPreferred list; they are ExxonMobil and Fuchs.

For reference, the 20 largest lubricant manufacturers are shown below, in decreasing order of capacity:

Shell ; ExxonMobil ; BP ; Chevron ;
Petrochina Sinopec ; Lumoil ; Total ; Fuchs ;
Nippon Oil Idemitsu ; Valvoline ; Conoco
Philips ; Petronas
CPC ; Petramina ; PDVSA ; Repsol ; SK Corp. ; Indian Oil

CONCLUSIONS AND OUTLOOK

Bio-lubricants have been increasingly successful in displacing mineral oil products in the areas of transformer fluids, elevator and other hydraulic fluids and metal rolling oils. Except for transformer fluids, the use of bio-lubricants only represents a small part of the total amount of lubricant used at this time. The amounts of bio-lubricants used per year in these areas are estimated at:

Transformer fluids:	6,000,000 gallons
Hydraulic fluids:	2,000,000 gallons
Bar and chain oils:	100,000 gallons
Railroad greases:	50,000 gallons
Wire rope:	20,000 Gallons
2-cycle oils:	20,000 gallons

2013. In 2012, estimates of the use of conventional soybean oil in lubricant applications had increased to over 12 million gallons primarily in the uses above. Transformer fluids, hydraulic fluids and metal working fluids remained the most significant uses. The impact of high oleic soybean oil will depend on the availability and price of the material.

HOSO is not expected to have any material impact on the transformer fluid market. Increased use of HOSO as a triglyceride in hydraulic fluids and metal working fluids could rapidly increase lubricant share by 10-15 million gallons or more. If synthetics made from HOSO are successful as basestocks for crankcase oils and are priced at or below polyalphaolefins the potential to increase by an additional 20 million gallons or more is real, according to industry experts.

The present lack of US regulations mandating the use of bio-lubricants in environmentally sensitive areas is major hurdle to be overcome of this area. The requirements of the 2002 Farm Bill and subsequent legislative initiatives, which are just coming into force in the lubricants area, is a start toward an “Eco-labeling” program such as is prevalent in Europe. Although marginally effective today, it should become more of a factor in the future.

The lack of regulatory pressures which mandate adoption and generally premium prices makes it difficult for suppliers to compete and for these areas to grow. This situation is changing as successes get more publicity. These vegetable-based lubricants are
beginning to be considered as true alternatives to mineral oil products. The absence of bio- lubricant products from the major lubricant suppliers suggests that they have yet to decide that this area is large enough to justify their commercial participation at present.

It is believed that the bio-lubricant area will grow faster in the next years ahead than has been experienced in the years since the initial 1997 study. There are two main factors that would make this happen.

1- The availability of commercial quantities of high oleic soybean oil (HOSO) will lead to more stable and better performing products in all classes of lubricants. This would make soybean oil-base products more functionally competitive with rapeseed and mineral oil-based lubricants.

2- The federal government BioPreferred program will require all agencies to report quantitative data on their use of such products - which ones and how much. This transparency will promote the use of these products in all areas of the government as well as in the private sector.

As a forecast, it is estimated that growth of bio-based lubricant products and fluids will be in the range of 5-8% per year.

APPENDIX

Environmental and Regulatory Review

- Federal Oil Pollution Prevention Regulations
- Reporting Requirements – Oil Spills and Hazardous Substance Releases
- Spill / Release Cleanup Requirements
- Waste Management
- Environmental Fate of Used Soybean Oil Lubricants

APPENDIX

ENVIRONMENTAL AND REGULATORY REVIEW

FEDERAL OIL POLLUTION PREVENTION REGULATIONS

The U.S. Environmental Protection Agency (EPA), under the authority of the Clean Water Act and the Oil Pollution Act, regulates spill prevention, preparedness, and response planning for both petroleum and non-petroleum oil that has the potential to be or is discharged into U.S. navigable waterways and adjacent shorelines. Requirements include:

- **The Spill Prevention, Control, and Countermeasure (SPCC) Rule**. This rule requires facilities that have oil storage capacity above certain sizes (i.e., above ground oil storage capacity greater than 1,320 gallons and buried oil storage capacity greater than 42,000 gallons) to prepare and implement plans to prevent any discharge of oil into or upon navigable waters of the United States or adjoining shorelines. The plans must include: operating procedures the facility implements to prevent spills; control measures to prevent oil from entering navigable waters or adjoining shorelines; and countermeasures to contain, cleanup, and mitigate the effects of an oil spill.

- **The Facility Response Plan (FRP) Rule.** This rule requires facilities (ones that store or use oil that could reasonably be expected to cause "substantial harm"[1] to the environment if discharged into or on navigable water) to prepare plans that demonstrate a facility's preparedness to respond to a worst-case oil discharge.

Oil is defined to mean oil of "any kind or in any form, including, but not limited to: fats, oils, or greases of animal, fish, or marine mammal origin; **vegetable oils**, including oils from seeds, nuts, fruits, or kernels; and, other oils and greases, including petroleum, fuel oil, sludge, synthetic oils, mineral oils, oil refuse, or oil mixed with wastes other than dredged spoil." Vegetable oil is defined as " a non-petroleum oil or fat of vegetable origin, including but not limited to oils and fats derived from plant seeds, nuts, fruits, and kernels."

In 1995, Congress passed the Edible Oil Regulatory Reform Act. The Act directed federal agencies that issue or enforce a regulations to differentiate between and establish separate categories for animal fats, vegetable oils, and other oils, including petroleum oil; and apply different standards to different classes of fats and oils based on differences in physical, chemical, biological, and other properties, and in the effects on human health and the environment.

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[1] According to EPA, a facility may pose "substantial harm" for the purpose of the Facility Response Plan (FRP) rule if it: (1) has a total oil storage capacity greater than or equal to 42,000 gallons and it transfers oil over water to/from vessels; or (2) has a total oil storage capacity greater than or equal to one million gallons and meets one of the following conditions; (a) does not have sufficient secondary containment for each aboveground storage area; (b) is located at a distance such that a discharge from the facility could cause "injury" to fish, wildlife, and sensitive environments; (c) is located at a distance such that a discharge from the facility would shut down a public drinking water intake; or (d) has had, within the past five years, a reportable discharge greater than or equal to 10,000 gallons.

In 1997, EPA denied a petition previously filed by several trade organizations and agricultural groups requesting that EPA amend its Facility Response Plan rule to create a different regulatory program for non-petroleum, "non-toxic" oils different from the program for petroleum oils and "toxic" non-petroleum oils. EPA took the position that, even using the evaluation criteria under the Edible Oil Regulatory Reform Act (i.e., physical, chemical, biological, and other properties and environmental effects), "petroleum oils, vegetable oils, and animal fats share common physical properties and produce similar environmental effects" when discharged into navigable waters or adjoining shorelines. EPA states that "like petroleum oils, vegetable oils and animal fats and their constituents can:

- Cause devastating physical effects, such as coating animals and plants with oil and suffocating them by oxygen depletion
- Be toxic and form toxic products
- Destroy future and existing food supplies, breeding animals, and habitats
- Produce rancid odors
- Foul shorelines, clog water treatment plants, and catch fire when ignition sources are present
- Form products that linger in the environment for many years."

Therefore, for the purpose of its Oil Pollution Prevention regulations (i.e., the SPCC and FRP rules), EPA regulates both petroleum oil and vegetable oils in generally the same manner. In a few limited situations, EPA treats vegetable oils differently. Under the FRP rule, which was revised in 2000, EPA included "a more specific methodology for calculating planning volumes for a worst case discharge of animal fats and vegetable oils." According to EPA, "the methodology is similar to that currently used in the rule for petroleum oils, but the factors in two new tables are more appropriate for estimating on-water and onshore recovery resource needs for animal fats and vegetable oils."

REPORTING REQUIREMENTS - OIL SPILLS AND HAZARDOUS SUBSTANCE RELEASES

Federal regulations require release and spill reporting for both oil and hazardous substances. There are separate requirements for oil spills and hazardous substance releases.

- **Oil Spill Notification.** Facilities are required to report immediately to the National Response Center discharges of harmful quantities of oil to navigable waters. A "harmful quantity" of oil is defined as "any quantity causing a film or sheen on the receiving waters, any quantity causing a sludge or emulsion to be deposited beneath the surface of the water or upon the adjoining shorelines, or any quantity that violates an applicable water quality standard."

- **Hazardous Substance Release Notification.** For hazardous substances, the federal government requires reporting to the National Response Center when a listed substance is released to the environment at an amount that equals or exceeds the “reportable quantity” (RQ) for that substance. There are about 800 substances that have RQs. “Release” is defined to mean any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment....” Neither petroleum oil nor vegetable oil are listed hazardous substances, however, constituents of petroleum (e.g., benzene, toluene, xylene) are listed as hazardous substances and other substances that might be constituents of additives used in ether petroleum or vegetable oil-based formulated products are also listed.

Most states also have their own reporting requirements that cover oil and hazardous substances spills to water and/or the land. At a minimum, for oil spills into waterways these requirements are at least as stringent as the federal spill requirements and for releases of hazardous substances to land or water these requirements are at least as stringent as the federal hazardous substance release notification requirements. A number of states, however, have more stringent spill reporting requirements that require reporting at lower release quantities. In general, state spill reporting regulations do not differentiate between petroleum oil and vegetable oil.

Therefore, for the purposes of spill reporting:

- Federal oil spill reporting requirements (into waterways or adjacent shorelines) do not differentiate between vegetable oil and petroleum oil.

- Federal hazardous substances release reporting (to land or water) is based on the quantity of individual listed chemical substances contained in the spilled/released product. To the extent that vegetable oil-based lubricants contain none of the listed hazardous substances or contain them at lower levels than petroleum-based products, spills of vegetable oil-based products may not need to be reported under federal hazardous substance release notification regulations.

- A number of states have more stringent reportable quantities for spills of oil and/or releases of hazardous substances so that smaller spills/releases may need to be reported to states for both petroleum and petroleum-based products and vegetable oil and vegetable oil-based products.

SPILL / RELEASE CLEANUP REQUIREMENTS

Federal cleanup requirements for oil spills and hazardous substance releases are contained in the Federal National Contingency Plan (NCP).

- For oil spills, the NCP directs the on-scene coordinator (OSC) “to determine whether a release poses a substantial threat to the public health or welfare of the United States based on several factors, including the size and character of the discharge and its proximity to human populations and sensitive environments. In such cases, the OSC is authorized to direct all federal, state, or private response and recovery actions. The OSC may enlist the support of other federal agencies or special teams."

- For hazardous substance releases, the NCP provides that "decisions of action will be based on threats to human or animal populations, contamination of drinking water supplies or sensitive ecosystems, high levels of hazardous substances in soils, weather conditions that may cause migration or release of hazardous substances, the threat of fire or explosion, or other significant factors effecting the health or welfare or the public or the environment."

For spills not covered by the federal response and reporting requirements, state cleanup standards would apply. State standards, particularly as they relate to land releases, are often based on meeting certain risk-based cleanup levels (e.g., the level of hazardous constituents remaining in the soil after a release).

In summary:

- The federal NCP does not provide a one size fits all cleanup response. Responses are based on the size and the nature of the spill. Responses could, and in many cases will (particularly in the case of small and medium size spills), vary for vegetable oil/vegetable oil-based lubricant products compared to petroleum/petroleum-based lubricant products based on ecotoxicity properties and rates of biodegradation.

- State regulations are most likely to cover the type of smaller releases, particularly to the land, associated with the use of lubricant products. Because state cleanup standards are usually based on risk, spills of vegetable oil-based products that are less toxic and more biodegradable are much less likely to require any significant cleanup action. Practical experience with state and local government regulators' responses to spills of vegetable oil-based hydraulic fluids, for example, support this conclusion.

WASTE MANAGEMENT (see also *Environmental Fate of Used Soybean Oil Lubricants in following Appendix section)*

At the federal level, "used oil" is managed under a set of standards (40 CFR 279) developed by EPA under the Resource Conservation and Recovery Act (RCRA). "Used oil" is defined by EPA as "any oil that has been refined from crude oil, or any synthetic oil, that has been used and as a result of such use is contaminated by physical or chemical impurities." Animal or vegetable oils (including when used as a lubricant) are <u>excluded</u> from EPA's definition of used oil.

Oils refined from crude oil, or any synthetic oil, that have been used as lubricants, hydraulic fluids, heat transfer fluids, buoyants, or for other similar purposes (e.g., engine oil, transmission fluid, metalworking fluids and oils, electrical insulating oil, and industrial process oils) and that are sent for “recycling” in accordance with EPA’s used oil regulations are excluded for the federal definition of “hazardous waste.”[2] Used oil that is not recycled in accordance with federal standards is subject to being managed as a hazardous waste if it meets the regulatory definition of a hazardous waste (e.g. contains levels of lead, cadmium or other EPA listed metals and chemicals above certain levels).

EPA’s used oil regulations allow for four types of “recycling”:

- reconditioning the oil on site to remove impurities;
- using the oil as a feedstock going into a petroleum refinery;
- re-refining the oil into a new base stock; or
- processing and burning the oil for energy recovery.

Generators, collection centers, transporters, transfer facilities, processors and refiners, and marketers are all subject to the used oil management standards. In particular, generators of used oil who send their oil for recycling are subject to the following requirements:

- meeting all applicable Spill Prevention, Control and Countermeasures program requirements;
- storing the used oil in tanks, containers, or RCRA-regulated units (e.g., lagoons, pits, surface impoundments);
- marking “used oil” on the container and tanks;
- keeping tanks and containers in good condition and free from leaks;
- responding to, stopping, and cleaning up releases; and
- having used oil transported by a regulated transporter or meeting self-transporter requirements.

Under current federal regulations, therefore, the waste management requirements for vegetable oil- based lubricant and fluid products require careful review. If a formulated product contains no petroleum or synthetic base oils, it would not be subjected to the used oil management standards. However, the vegetable oil-based product would still need to be assessed after its use to determine if it contains any contaminants that would classify it as a “hazardous waste.” Assuming the product contained no such contaminants, it could be managed as a solid waste, providing a potentially broader array of waste management options for the used product (such as burning in small waste heat units).

If a formulated product contains both vegetable oil base stock and petroleum or synthetic oil base stock, under federal regulation the waste management of the used product would

[2] Used oil that is mixed with a listed hazardous waste must be managed as a hazardous waste. Used oil that contains more than 1,000 ppm of total halogens is presumed to have been mixed with a listed hazardous waste unless the generator can show through documentation that the halogens were not the result of being mixed with a listed waste. Used oil containing more than 50 ppm of polychlorinated biphenyls (PCBs) cannot be managed under the RCRA used oil standards but instead must be managed under Toxic Substances Control Act regulations.

be subject to the used oil management standards. Recycling used oil under the federal management standards would exempt the generator from managing the oil as a hazardous waste and therefore provide a less costly method of managing the waste oil. Alternatively, as with a product made using a 100% vegetable oil base stock, if the “mixed” oil product after it is used does not contain any contaminants that would classify it as a “hazardous waste,” it could be managed as a solid waste.

In addition to federal standards, certain states have adopted used oil management standards that are more stringent than the federal standards. Also, the regulatory status of vegetable oil under state programs could vary from the federal regulations and would need to be assessed separately.

ENVIRONMENTAL FATE OF USED SOYBEAN OIL LUBRICANTS

The environmental fate of used lubricating oils made with a soybean oil base stock somewhat parallels that for 100% based petroleum oils. Used petroleum oils are typically collected and are either re-refined, blended as a supplemental thermal energy feedstock for industrial furnaces, sprayed on coal for dust control or used as rust prevention or friction reduction coatings. Factors influencing the choice for environmental fate include:

- Availability of a facility to re-refine used oil
- Transportation distance to a re-refining oil facility
- Availability of an industrial furnace with appropriate air pollution control equipment to handle emissions from used oil combustion
- Internal uses for used oil
- Economics for the life cycle phases of oil production, use and reuse

Environmental Fate Choices

Re-refining

When economically feasible, used oils and lubricants are collected and transported to a petroleum oil re-refining facility. There are no facilities dedicated to re-refining biobased lubricants due to their relatively low volumes. Most collection practices do not segregate biobased oils from petroleum oils and lubes unless the volumes dictate otherwise. If any used oil collection segregation is employed, it is usually for oils that contain emulsified or oil/water mixtures. Thus, it can be expected that used soybean oil lubes would ultimately be mixed with petroleum based lubes either at the customer’s facility or in the collection truck before going to the re-refining facility.

Current re-refining facilities for used petroleum oils are not equipped to separate and recover the soybean oil lube fraction from a mixture of oils. Petroleum re-refiners are reluctant to accept greater than 2% biobased lubes in their incoming mixtures due to a concern for degrading the oxidation stability of the base oil they produce. However, there is no data available to substantiate this allegation.

If soybean oil lubricant is present in an incoming mixture, the soybean oil component would be separated from the desired petroleum fraction due to the higher boiling point difference of the soybean oil. This higher boiling fraction would include higher boiling petroleum fractions and be used as an industrial fuel oil feedstock.

Industrial Furnace Applications

Where re-refining facilities are too distant for economical transport, used oils are commonly used as a low cost fuel feedstock for industrial furnaces such as aggregate dryers at asphalt plants, cement kilns and blast furnaces. These types of furnaces are fitted with the appropriate kind of air pollution control equipment to limit particulate emissions. These types of furnaces can accommodate a high ratio of soybean oil lubricants in the fuel feedstock.

Other Uses

Used soybean oil lubricants can be use for applications such as dust control for coal and aggregate transported in rail cars and storage piles and as a “once-through” lubricant for oven bearings and chains.

Summary

Based on economics and ease of handling, the most common “end-of-life” option for used soybean oil lubricant products is to utilize them as a supplemental fuel source for industrial furnaces. This option offers the widest availability of beneficial users and is competitive with used petroleum based lubricant environmental fate options.